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Research
Theme
Analysis
Report

Cooperative Intelligent Transport Systems

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Portal

Research Theme Analysis Report

Cooperative Intelligent Transport Systems

Contents

Executive summary

This Research Theme Analysis Report provides a review of research projects under the new Transport Research & Innovation Portal (TRIP) Continuation project for the European Commission's Directorate-General for Mobility and Transport (DG-MOVE). It covers the Cooperative Intelligent Transport Systems (C-ITS) research theme.

The purpose of TRIP is to collect, structure, analyse and disseminate the results of EU-supported transport research, research financed nationally in the European Research Area (ERA), and selected global research programmes. The TRIP web portal can be found at www.transport-research.info.

This research theme analysis report gives an overview of research performed (mostly) in the EU collated by TRIP, providing a view across many projects that fall under the theme title. It provides an assessment of the reported results from these projects and offers perspectives from scientific and policy points of view.

Intelligent transport systems (ITS) refers to the application of information and communication technologies (ICT) to the transport sector. ITS integrate telecommunications, electronics and information technologies with transport engineering to plan, design, operate, maintain and manage transport systems. It can have applications in a range of fields including infrastructure, vehicles and users, traffic and mobility management and interfaces with other modes of transport.

Cooperative ITS (C-ITS) is a subset of ITS that has been defined by the European Committee for Standardization (CEN) TC278 WG16/ISO TC204 WG18 and European Telecommunications Standards Institute (ETSI) EC ITS together as:

'A subset of the overall ITS that communicates and shares information between ITS stations to give advice or facilitate actions with the objective of improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems.'

For the purpose of this review, the theme of C-ITS has been divided into 10 sub-themes and the assessments performed within each sub-theme as well as across the complete C-ITS theme. The 10 sub-themes considered are:

- communication technologies;

- data protection and security;

- freight transport and logistics;

- human-machine interaction;

- information systems/platform;

- motorway applications;

- public transport;

- safety, efficiency and emissions;

- sensors;

- urban applications.

The key findings from a **scientific perspective** are:

- While motorway applications of C-ITS have in general reached a high degree of technological maturity with many of them being used in large-scale pre-commercial deployments, less progress has been made in C-ITS services for urban,

freight or public transport applications. Efforts to bring these services to a commercial level of maturity should continue – for example through the integration of urban-related services with future urban mobility plans.

- The increase in levels of vehicle automation has important legal implications on the attribution of liability and compatibility with existing legislation, particularly as the more advanced C-ITS services begin to be deployed following the initial applications.

- While much progress has been made on the security and certification of C-ITS, there remains a significant body of work to be done including developing a single common standardised EU trust model and certificate policy and international cooperation on interoperability.

- Organisational principles to ensure interoperability (e.g. data management, data ownership and system reliability) remain poorly developed, with strong disagreement between stakeholders highlighted by the C-ITS Platform final report[1] on access to data, ownership, responsibility for running data services, etc.

- To avoid a fragmented approach to deployment and hence be better able to take advantage of network effects and the single market, national and regional business cases for the deployment of C-ITS need to be developed further. The role of incentives and other methods to foster deployment should also be further examined by the relevant authorities.

- Communication and education is needed to inform the public about the technological possibilities, benefits and contribution to societal goals to ensure acceptance and to mitigate fears.

- To maximise the potential of C-ITS in an increasingly global market, international cooperation will benefit industry and the public sector. There are agreements for cooperation between Europe, the USA and Japan. International cooperation activities are also supported by different European Commission Seventh Framework Programme (FP7) support action projects as well as by the C-ITS Platform itself. Further work here is also recommended in the C-ITS Platform final report.

The key findings from a **policy perspective** are:

- Progress is ongoing in the definition of standards relevant to communication technologies and this is expected to continue as C-ITS services mature. Research projects in this area highlighted the importance of involving stakeholders throughout the development process to ensure a more efficient deployment of C-ITS throughout Europe.

- Travellers generate massive quantities of detailed information (individual, activity, travel and location) through a variety of channels. This increases the exposure and possibility of inappropriate use of individual information, which raises significant concerns on data privacy, protection and security. Policy developments may be required to address data collection and security issues relating to autonomous and connected vehicles.

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[1] http://ec.europa.eu/transport/themes/its/doc/c-its-platform-final-report-january-2016.pdf

- The provision of in-vehicle information through tangible, acoustic and visual channels have enabled the smooth introduction of driver assistance systems. By disseminating these systems further, adding vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication and integrating multiple vehicle information systems (without overloading the driver with information), may help in approaching the zero fatality vision pursued by some Member States and by the European Commission's 2011 Transport White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' (EC, 2011).

- To achieve the potential benefits for improved public transport services, there is a need for greater consistency in regulations across Member States to allow for informed planning of public transport services that ensure interoperability.

The **priority research gaps** identified are:

- Research to establish widely accepted data and privacy security protocols for use in C-ITS services and their underlying communications technologies.

- Research on how to resolve the 'chicken and egg' problem on stimulating investment and on identifying viable business models in the sector - particularly at a more local or regional level where investment decisions will be made.

- Integrating C-ITS service deployment plans into cities' long-term urban planning and transport regulation agendas. This will enable better and easier use of C-ITS services and achieve maximum impacts by deploying newer and better services for travellers in the context of sustainable urban development.

- Improving the functional linkage of C-ITS applications as a core element of an integrated urban freight transport (UFT) scheme through increased cooperation between C-ITS and UFT projects.

- International coordination between the various parties is key to the deployment of C-ITS services and is essential to increase the efficiency and learning capacity of researchers and market parties, to reduce the knowledge divide among European regions and to increase the competitiveness of the European transport sector as a whole. Initiatives such as the C-ITS Platform will be vital in helping to ensure this cooperation.

Many of these issues are well aligned with the recommendations for additional work highlighted in the recent C-ITS Platform final report and continued efforts should be made to tackle them in a coordinated fashion.

In general, the analysis of the research being performed indicates there is relatively little overlap between many projects and programmes. Those overlaps which have been identified include:

- The main areas of research are driven primarily by the business sector and car producers. There is a risk associated with the isolated development of similar driver assistance systems with limited compatibility. It is also important to consider the effects of C-ITS on the safety of passengers (in private cars and public transport) and drivers of vehicles.

- The majority of research projects analysed in this study were funded by the EU and have a natural synergy and alignment with EU policy. An exception occurs in the topic of public transport. In this instance, many of the projects are nationally or locally driven initiatives to improve the public transport services offered to end-users and to optimise the fleet management and operations for the operating companies. Increased cooperation and interaction among the various national and local projects could form the basis for broader collaborative research programmes in the future.

The review suggests that a lot of good technical research has been carried out and that there is plenty of best practice at the implementation level. Key barriers to a greater application of the research include:

- the systems and their interfaces need to be standardised to ensure compatibility of V2V and V2I communications between systems from all manufacturers;

- the potential consequences on building the capacity of the C-ITS infrastructure and market fragmentation if the required standardisation is not achieved (or is delayed until after the launch of the first generation of systems and services);

- there is a lack of user and stakeholder awareness and a low societal acceptance of the systems;

- some systems (especially those based on V2V technologies) will be functional and effective only when a sufficient proportion of the vehicle fleet (or even all vehicles) is equipped;

- the future development of transport and C-ITS is difficult to predict for a longer period, leading to investment concerns;

- legal issues related to data privacy;

- an established and recognised methodology for testing applications that are not commercially deployed.

Recommendations made from this review, with the aim of further improving the outputs from the research on C-ITS, include:

- Communication technologies – the technical and social factors that should be explored in future research include:

  - an assessment of the performance of next generation communication technologies, their applicability to connected transport applications and the costs associated with their use;

  - the definition of relevant standards as communication technologies develop to ensure a consistent approach across Europe and maintain interoperability;

– an investigation of the security and privacy/data protection challenges associated with the use of different communication technologies;

– research into technical factors such as the latency and reliability of communication technologies and improvements to them, especially where there are high levels of deployment of C-ITS services in congested areas.

- Data protection and security – further research is required to establish common methodologies, data protocols and standards for addressing issues of data protection and security among C-ITS services and their supporting technologies, including:

  – developing privacy metrics to quantify and compare levels of protection provided by different policies and security systems;

  – developing privacy requirements and standards in the context of data collection activities (using alternative instruments such as mobile device applications, travel surveys, automatic number plate recognition (ANPR) systems, smartcard readers, etc.);

  – large sample 'big data' analysis on a pan-European level that will allow comparisons of user awareness and expectations regarding data sharing, privacy and security issues and adoption rates of ITS-related platforms and systems across EU countries.

- Freight transport and logistics – the requirements for future research identified with relevance to freight transport and logistics include:

  – investigating how to ensure the interoperability of sensors with a wide range of C-ITS services and advanced driver assistance systems, to allow increasingly complex services to be deployed that rely on information generated by several sensors;

  – investigating the potential for integrating applications in the V2I domain in systems that can be offered as a service for managing freight transport infrastructures;

  – researching commercial business models and integrated frameworks for linking connected vehicles to open and connected infrastructures, involving public and private infrastructures through 'collaborative logistics'.

- Human-machine interaction (HMI) – the priorities for future research into HMI include:

  – HMI for informing the driver of non-safety related traffic characteristics, such as congestion mitigation or fuel efficiency;

  – research the development of integrated vehicle and HMI concepts for all types of users, including the elderly and disabled;

  – research the requirements for data and privacy security of HMI interfaces, with particular reference to the potential presence of fully automated vehicles in the future.

- Information systems/platform – the priorities for future research into information systems and platforms include:

  – research into the development of systems capable of gathering, processing and enriching big data in real time, covering a mix of different information channels such as navigation systems, smartphones, infrastructure and in-vehicle devices.

- Motorway applications – the requirements for future research under motorway applications of C-ITS should include:

  – investigating the application of C-ITS motorway services to other vehicle types, such as freight and focused on improvements of non-safety aspects, such as congestion and fuel efficiency;

  – quantifying the wider costs and benefits of the C-ITS motorway applications under development to ensure that they can deliver benefits in a cost-effective manner;

  – placing a greater emphasis on the publishing and sharing of the main research outputs;

  – investigate the user-acceptance of C-ITS under motorway conditions and determine improvements to the systems (including the HMI interface) to increase acceptance.

- Public transport – the key aspects of the application of C-ITS to public transport that require further research include:

  - integrating C-ITS and innovative transport services (such as car-sharing, automated bus services) with the core public transport network, in particular the ability to solve the 'first-kilometre, last-kilometre' problem;

  - investigating the role of C-ITS in the integrating automation into the public transport system;

  - developing multimodal travel planners using big data and advanced predictive analytics;

  - developing Mobility as a Service (MaaS) systems to provide integrated travel and payment services to travellers.

- Safety, efficiency and emissions – the priorities for future research on the safety, efficiency and emissions aspects of C-ITS should include:

  - perform in-depth analyses of the links between the intelligent vehicle systems and improvements in driver behaviour, fuel efficiency, traffic safety and overall cost savings;

  - investigate the risks to traffic safety related to the reliability of the C-ITS infrastructure, in particular how to overcome any potential collapse of the systems;

  - investigate the risks related to internet attacks (viruses, hackers) to the safety and security of the transport system;

  - develop guidance for policymakers, as well as transport engineers, to plan and invest in appropriate C-ITS (so improving safety, improving efficiency and reducing emissions), to clarify the market for specific ITS applications and to understand the barriers to implementation.

- Sensors – the priorities for future research into sensors for C-ITS should include:

  - investigate how the interoperability of different sensors can be achieved to provide efficient data fusion capabilities;

  - integrate sensing systems developed for advanced driver assistance systems (ADAS) applications with the communication technologies in C-ITS;

  - develop advanced sensors and the use of the data provided by them for non-safety-related benefits (such as fuel efficiency, emissions) and for a greater variety of vehicle types (beyond passenger cars).

- Urban applications – the priorities for future research into urban applications of C-ITS include:

  - developing urban C-ITS services to a similar level of maturity as motorway services to help overcome the various transport-related issues affecting cities in the EU;

  - investigating integration issues between C-ITS services and urban transport, including emerging technologies and trends such as integrated public transport and sharing services, multimodal mobility, MaaS, crowdsourcing and iBeaconTM technologies.;

  - investigating the application of big data collection and analysis activities to support the future of urban mobility, such as dynamic measurements via smartphones, visualisations and analyses using large-scale data and market demand analyses for public mass transportation;

  - investigating the processes and traffic flow mechanisms within an urban environment related to:

    > influence on traffic capacity (smoothing the flow);

    > reliability of the systems under different traffic conditions;

    > adaptation to and interaction with the traffic environment;

    > effects of coupling between different systems;

    > safety (looking at the driver behaviour and traffic processes, developing a long term database of incidents);

  - investigating how to improve user acceptance and understanding of new technologies.

1 Introduction

This is the second in the new series of research theme analysis reports produced under the new Transport Research & Innovation Portal (TRIP) continuation project for the European Commission's Directorate-General for Mobility and Transport (DG-MOVE). It covers the Cooperative Intelligent Transport Systems (C-ITS) research theme.

The purpose of TRIP is to collect, structure, analyse and disseminate the results of EU-supported transport research, research financed nationally in the European Research Area (ERA) and selected global research programmes. The TRIP web portal can be found at www.transport-research.info

This research theme analysis report gives an overview of research performed (mostly) in the EU collated by TRIP, providing a view across many projects that fall under the theme title. It provides an assessment of the reported results from these projects and offers perspectives from scientific and policy points of view.

This assessment aims to consider:

- overall trends in C-ITS research, including key results;
- overall trends in the research funding;
- the alignment of the research with current policy;
- policy implications of the results from the research;
- any gaps in the research theme.

The assessments for this analysis have been performed on a number of sub-themes within the theme of C-ITS. The projects identified have been clustered under these sub-themes. The analyses of the trends and gaps have been performed across the projects in the sub-themes and across the full C-ITS theme. The set of sub-themes, selected following initial assessments of the projects, comprises:

- communication technologies;
- data protection and security;
- freight transport and logistics;
- human-machine interaction;
- information systems/platform;
- motorway applications;
- public transport;
- safety, efficiency and emissions;
- sensors;
- urban applications.
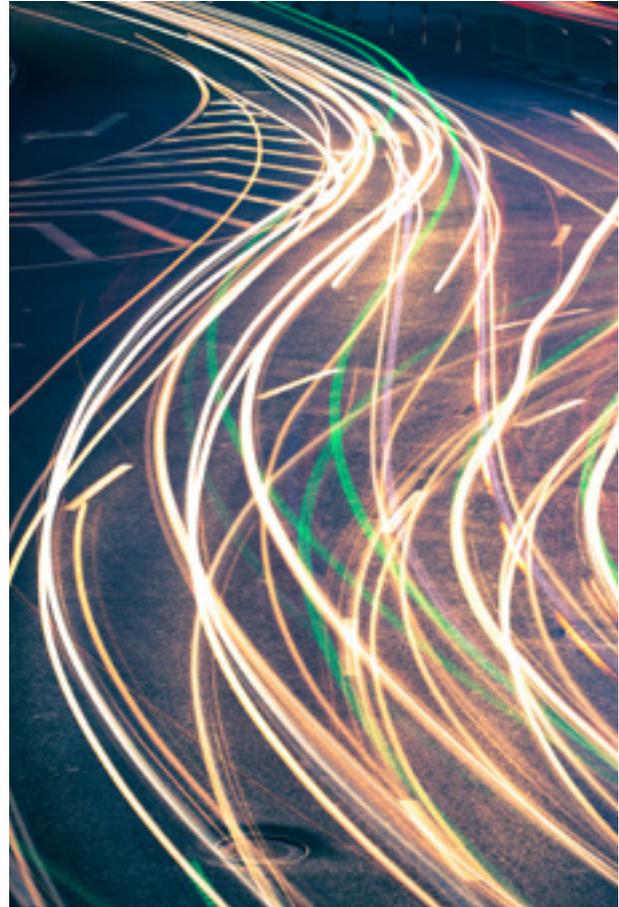
By the nature of the analysis being performed, the assessments of trends and gaps are based on the projects selected (primarily) from those within the TRIP and do not take account of the results of research that was not identified through this process. Additional projects have been identified in the course of this analysis and these will be added to the TRIP database. It should be noted that European Commission-funded projects are naturally aligned with EU policy through the funding and selection process. As such, the trends identified from these projects may not necessarily be representative of those from further afield.

Section 2 of this report presents a high-level review of the C-ITS theme, and includes policy and research highlights. The subsequent sections then present reviews of the individual sub-themes (as specified above) including preliminary recommendations, the research environment and development, and the research activities and outcomes. Conclusions and recommendations are then presented at the end of the report.

2 Policy and research highlights

2.1 Scope of the Cooperative Intelligent Transport Systems Theme

Intelligent transport systems (ITS) refers to the application of information and communication technologies (ICT) to the transport sector. ITS integrates telecommunications, electronics and information technologies with transport engineering to plan, design, operate, maintain and manage transport systems. It can have applications in a range of fields including infrastructure, vehicles and users, traffic and mobility management, and interfaces with other modes of transport.

Cooperative ITS (C-ITS) is a subset of ITS that has been defined by the European Committee for Standardization (CEN) TC278 WG16/ISO TC204 WG18 and European Telecommunications Standards Institute (ETSI) EC ITS together as:

> 'A subset of the overall ITS that:
>
> - Communicates; and
>
> - Shares information
>
> Between ITS stations to:
>
> - Give advice; or
>
> - Facilitate actions.
>
> With the objective of improving safety, sustainability, efficiency and comfort beyond the scope of stand-alone systems.'

That is, C-ITS is characterised by the sharing of data between different applications, greatly increasing the quality and reliability of information. Therefore, C-ITS has the potential to further increase the benefits of ITS services and applications.

In road transport, C-ITS typically involves communication between vehicles (vehicle to vehicle (V2V)), between vehicles and infrastructure (vehicle to infrastructure (V2I)) and between vehicles and other road users (V2X), such as pedestrians and cyclists:

- **V2V C-ITS services** involve organising the interaction between vehicles and possibly developing collaborations among them. V2V can transmit messages about a vehicle's speed, direction of travel, brake status and other information to other vehicles, and receive the same type of information from other vehicles. This provides a longer detection distance (than, for example, the driver's eyesight would provide) and the ability to 'see' around corners or 'through' other vehicles, helping V2V-equipped vehicles identify some threats sooner than sensors, cameras or radar can and warns their drivers accordingly. This results in capabilities that exceed current and near-term, in-car technologies (such as electronic stability control, lane departure warnings, adaptive cruise control (ACC), blind spot detection, rear parking sonar and reversing cameras) because V2V technologies provide a 360° awareness of surrounding threats.

- In **V2I C-ITS services**, the infrastructure plays a coordinating role by gathering information on traffic and road conditions, and suggesting or imposing certain behaviours on a group of vehicles. Suggestions to drivers could be made via road displays and actions could be imposed on vehicles via wireless connections or through the vehicle controls and implemented semi-automatically. V2I communications are being developed that involve the wireless exchange of critical safety and operational data between vehicles and highway infrastructure with the aim of avoiding collisions and enabling a wide range of mobility and environmental benefits. For example, data may be used by the public sector to predict travel times along routes, identify incident locations and areas that need to be gritted, and inform drivers about changes in traffic and road conditions.

- New services that extend to vulnerable road users have also been announced, such as vehicle-to-pedestrian or vehicle-to-motorcycle (V2X) services. For example, mobile devices carried by pedestrians, such as smart phones, communicate with technology in vehicles so that the driver and pedestrian can be warned of any possible conflicts. For example, Honda has demonstrated a system based on dedicated short-range communications (DSRC), which uses information broadcast by smart phones carried by pedestrians (such as position and direction of travel). At intersections or crossings where pedestrians and drivers cannot see each other, Honda's system alerts both parties to the risk of a collision. Honda has demonstrated a similar technology for motorcycles. During research projects, motorcycles were fitted with vehicle awareness devices that enabled other vehicles equipped with V2V technology to detect them and alerts were produced if a possible collision situation arose.

Under this overall research theme, the following 10 specific sub-themes were identified to help categorise the research:

- communication technologies;

- data protection and security;

- freight transport and logistics;

- human-machine interaction;

- information systems/platform;

- motorway applications;

- public transport;

- safety, efficiency and emissions;

- sensors;

- urban applications.

Figure 2-1 Linkages and overlaps between the C-ITS sub-themes
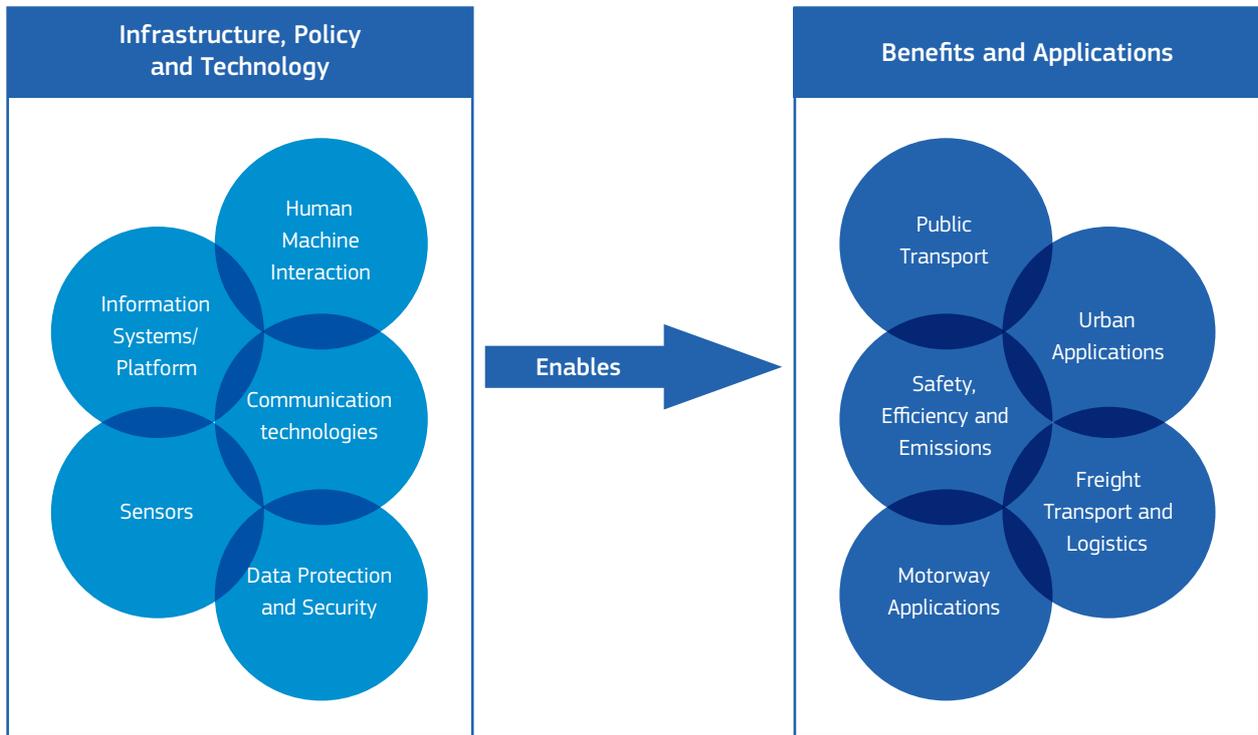
There are considerable linkages and overlaps between these themes, as shown in Figure 2 1. For example, freight transport and logistics, and public transport applications are closely linked to the safety, efficiency and emissions theme, while communications technologies, data protection and security, information systems/platform and sensors are relevant to all the other themes. However, each research sub-theme is relevant for discussion in its own right and is included as a separate sub-theme in the sections below.

2.2 Policy context

As outlined in the European Commission's Transport White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' (EC, 2011), the increasing road transport volumes in the EU are the primary cause of growing congestion of road infrastructure, rising energy consumption, and a source of environmental and social problems. Coordinated action across a number of fronts is required to tackle these issues and prevent them from becoming major influences on the European population, economy, environment and climate.

The development of new technologies aimed at improving the efficiency, safety and environmental performance of road transport is playing a significant role in achieving the Commission's goals in this area.

One such emerging field is that of C-ITS, which has seen remarkable new developments over the past decade supported by a range of policy measures. The policy context has developed around the need to address the fundamental challenges to C-ITS development and deployment.

2.2.1 R&D and demonstration funding

For many years, the European Commission has provided substantial support to European research and technology development (R&D) through its framework programmes. Earlier projects within the European R&D framework programmes mainly involved systems that were aimed at improving either the transport infrastructure or the vehicles themselves: these projects generally developed autonomous or standalone systems, either in the vehicle or at the roadside. From the outset of the European Commission's Sixth Framework Programme (FP6), it was recognised that the future of ICT applications in transport for safety and efficiency lay in cooperative systems. Funding support for C-ITS is available through **Horizon 2020**, and for infrastructure under the **Connecting Europe Facility** grant scheme and innovative financial instruments. Recently, a number of large-scale early deployment projects have been supported by these facilities, such as the Système Coopératif Pilote @ France[2] (SCOOP@F) and NordicWay[3] projects.

2   https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/projects-by-country/multi-country/2014-eu-ta-0669-s

3   https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/projects-by-country/multi-country/2014-eu-ta-0060-s

2.2.2 European Commission action plans and directives aimed at C-ITS

On 16 December 2008, the European Commission adopted an Action Plan for the Deployment of Intelligent Transport Systems in Europe (EC, 2008), which outlines six priority areas and the related measures for speeding up the deployment and interoperability of ITS in road transport across the European Union.

This Action Plan was the basis for Directive 2010/40/EU (the ITS Directive), which provides the legal framework for the implementation of the actions required for an effective and coordinated deployment and use of ITS. Article 2 of the Directive defines four priority areas for the development and use of specifications and standards:

- optimal use of road, traffic and travel data;

- continuity of traffic and freight management ITS services;

- ITS road safety and security applications;

- linking the vehicle with the transport infrastructure.

Within the priority areas, it also defines six priority actions for the development and use of specifications and standards:

- the provision of EU-wide multimodal travel information services;

- the provision of EU-wide real-time traffic information services;

- data and procedures for the provision, where possible, of road safety related minimum universal traffic information free of charge to users;

- the harmonised provision for an interoperable EU-wide eCall;

- the provision of information services for safe and secure parking places for trucks and commercial vehicles;

- the provision of reservation services for safe and secure parking places for trucks and commercial vehicles.

Many of these priority areas and actions are strongly aligned with the services available from the deployment of C-ITS. Several relevant initiatives have been implemented under the ITS Directive including the adoption of a series of delegated acts supplementing Directive 2010/40/EU – which requires the Commission to adopt delegated acts for each of the priority actions outlined above. These delegated acts include:

- Commission Delegated Regulation 305/2013 supplementing Directive 2010/40/ with regard to the harmonised provision for an interoperable EU-wide eCall. It is expected that, by reducing the response time of the emergency services, the interoperable EU-wide eCall will reduce the number of fatalities in the EU as well as the severity of injuries caused by road traffic collisions. It is also expected to bring savings to society by improving incident management and by reducing road congestion and secondary incidents.

- Commission Delegated Regulation 886/2013 with regard to data and procedures for the provision, where possible, of road safety-related minimum universal traffic information free of charge to users. The aim of the Regulation is to ensure interoperability and continuity of the information services along the trans-European road network.

- Commission Delegated Regulation 885/2013 containing specifications on the provision of information services on safe and secure parking places for trucks and commercial vehicles. Amongst other improvements, it is intended to prevent dangerous parking of trucks on the hard shoulder and to help drivers comply with driving time regulation across Europe.

- Commission Delegated Regulation 2015/962 with regard to the provision of EU-wide real-time traffic information services. It provides appropriate framework conditions enabling the cooperation of all the relevant stakeholders (road authorities, road operators and ITS service providers) involved in the traffic information value chain, and to support the interoperability, compatibility and continuity of real-time traffic information services across Europe.

Article 16 of the ITS Directive states 'The Commission shall establish a European ITS Advisory Group to advise it on business and technical aspects of the deployment and use of ITS in the Union'. In response to this, the C-ITS Platform was established in late 2014 late 2014 to assist the Commission to develop a shared vision and a roadmap for the deployment of C-ITS in the EU. The C-ITS Platform includes public and private stakeholders, and representatives from all of the key stakeholders along the C-ITS value chain including public authorities, vehicle manufacturers, suppliers, service providers and telecommunications companies.

Members of the C-ITS Platform's first phase met regularly throughout 2015 in a series of 10 working groups covering:

- cost-benefit analysis;

- business cases;

- legal issues;

- data protection and privacy;

- security and certification;

- technical issues:

  - access to in-vehicle data and resources;

  - decentralised congestion control;

  - hybrid communications and spectrum allocation;

- standardisation;

- public acceptance;

- implementation issues;

- international cooperation.

Within the C-ITS Platform, the working groups dedicated to these issues developed a common vision on policy recommendations and proposals for action for the Commission and other relevant actors along the C-ITS value chain. In January 2016[4], a final report was issued that summarised the C-ITS Platform members' contributions towards a shared vision on the interoperable deployment of C-ITS in the EU aligned with each of the 10 topics listed above.

The final report also makes recommendations to the Commission on the development of further actions and measures aimed at guiding the interoperable deployment of C-ITS in the EU. It suggests that this should be achieved along a well-defined timeline, with clearly stated goals, objectives and actions that are needed to support the successful deployment of C-ITS in the EU.

Drawing on the analysis carried out by members of the C-ITS Platform and on the recommendations in the final report, the Commission is now working to prepare an action plan by the end of 2016 that will set out the steps required for the successful deployment of C-ITS in the EU.

2.2.3 Broader political context within the EU

In the broader context of European-level objectives, C-ITS can contribute to the Europe 2020 Strategy[5] for smart, sustainable and inclusive growth. In particular, the flagship initiative 'Digital agenda for Europe', one of the seven pillars of the Strategy, sets out to define the key enabling role that the use of information and communication technologies (ICT) will have in helping to meet Europe 2020's goals and included several objectives for the rollout of ITS. Furthermore, another flagship initiative of the Europe 2020 Strategy, 'A resource-efficient Europe', sets out to create a framework for policies to support the shift towards a resource-efficient and low-carbon economy.

It is recognised that to achieve a resource efficient Europe:

- technological improvements are required;

- there needs to be a significant transition in energy, industrial, agricultural and transport systems (to more resource-efficient systems);

- as producers and consumers, we need to change our behaviours.

In the Transport White Paper, the Commission highlights traffic congestion, energy security and climate change as the major challenges for transport in the EU. One of the requirements of Initiative 16 of the Transport White Paper (Towards a 'zero-vision' on road safety) is to 'harmonise and deploy road safety technology – such as driver assistance systems, (smart) speed limiters, seat-belt reminders, eCall, cooperative systems and vehicle-infrastructure interfaces' by 2020. The Transport White Paper and the Communication 'Towards a European road safety area: policy orientations on road safety 2011-2020' (COM(2010) 389), set the ambitious target of halving the overall number of road fatalities in the European Union by 2020 (base year 2010) and presented seven strategic objectives to that end. One of these was to 'Promote the use of modern technology to increase road safety'.

The Communication 'A Roadmap for moving to a competitive low carbon economy in 2050' (COM(2011) 112)[6] complements the Transport White Paper and the Communication 'EU energy efficiency plan 2011' ((COM(2011) 109). It states that technological innovation can help the transition to a more efficient and sustainable transport system through the better use of networks, and safer and more secure operation through information and communication systems.

The potential for C-ITS to support innovation and competitiveness has long been recognised. For example, the automotive industry has established the Car 2 Car Communication Consortium, promoting a common industry-wide approach and agreement for harmonised implementation and deployment of C-ITS from 2015[7]. As part of the Commission's modern industrial policy, the Competitive Automotive Regulatory System for the 21st century (CARS21) Group was established to structure policy discussions on strategic issues. The CARS 21 Group recognised the potential for ITS and C-ITS to greatly improve road safety, mobility, comfort and sustainability, and called for greater coordination in this area[8]. The development of C-ITS will support the objectives of the renewed Lisbon Strategy and the Europe 2020 flagship initiative 'An industrial policy for the globalisation era' by facilitating the uptake of technologies, innovation and knowledge transfer, and promoting the sustainable use of resources.

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[4] http://ec.europa.eu/transport/themes/its/doc/c-its-platform-final-report-january-2016.pdf
[5] The European Union's 10-year jobs and growth strategy launched in 2010.
[6] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0112&from=EN
[7] Press release 10/2012: Vehicle Manufacturers signing MoU https://www.car-2-car.org/index.php?id=214
[8] Press release http://europa.eu/rapid/press-release_MEMO-12-419_en.htm

2.3 Research environment and development

Given the emerging nature of C-ITS and its supporting technologies (sensor, information and communication), the move towards commercialisation in the EU is heavily dependent on research programmes and associated funding. A substantial body of research is dedicated to C-ITS and this needs to be maintained to overcome the remaining challenges that are preventing full commercialisation in the EU.

Much of the research agenda is driven by the key priority areas and priority actions outlined in the ITS Action Plan and Directive[9] or by other concerns over the barriers to successfully deploying C-ITS services in the EU as highlighted in the C-ITS Platform final report. As such, a range of issues dominate the research agenda including:

- **Technical** – there is a variety of technical issues that could be enablers or barriers for the deployment of C-ITS – including telecommunication frequencies; hybrid communication technologies; decentralised congestion control; human/machine interfaces; information systems; and interfaces to infrastructure, urban transport frameworks, sensors and vehicle power systems. Many of these have been investigated extensively through research efforts, but some still remain (e.g. access to in-vehicle data as highlighted in the C-ITS Platform final report).

- **Standardisation and interoperability** – standardisation for C- ITS has already been initiated by CEN, ETSI and ISO, and other international standards organisations – all of which have developed relevant standards for use in C-ITS applications. The importance of the standardisation of C-ITS is clearly stated in the **EU standardisation mandate M/453**, which also recognises that to achieve the minimum penetration necessary for the systems and services to make a significant impact, it is essential to ensure their interoperability.

- **Security and certification** – a detailed security framework, impeding hacking, is needed to protect the various types of personal data that are generated by C-ITS services and their associated systems. Tamper-proof hardware and software security modules are required for the different parts of the systems, and standardised solutions are needed in line with EU Directive 95/46/EC[10] on the protection of individuals with regard to the processing of personal data and on the free movement of such data. There has been significant progress in carrying out the necessary preparatory work. However, a variety of unresolved issues remain, as highlighted in the recent C-ITS Platform final report.

- **Field operational tests (FOTs) and impacts analysis** – a number of projects have investigated the likely impacts of C-ITS services on safety, efficiency and the environment. These services cover a range of applications, with the strongest activity being for safety-critical applications. However, various trials of C-ITS services for specific types of transport (freight, urban and public) have also been conducted.

- **Pre-commercial deployments** – a number of projects have moved towards the pre-commercial deployment phase, particularly in the field of motorway-focused C-ITS services where significant progress has been made in linking major EU Member States via key Trans-European Transport Network (TEN-T) corridors.

While much progress has been made in tackling the various barriers to full-scale commercial deployment of C-ITS services, a number of research areas continue to require attention, including:

- **Non-motorway C-ITS service technological development** – while motorway C-ITS services have, in general, reached a high degree of technological maturity, with many being used in large-scale pre-commercial deployments, less progress has been made in C-ITS services for urban, freight or public transport applications. Efforts to bring these services to a commercial level of maturity should continue – for example, through the integration of urban-related services with future urban mobility plans.

- **Legal issues** – these include data protection, privacy and liability. The increase in levels of vehicle automation has important implications on the attribution of liability and compatibility with existing legislation, particularly as the more advanced post-Day 1 C-ITS services (i.e. beyond the initial commercial deployment) begin to be deployed.

- **Security and certification** – while much progress has been made, there remains a significant body of work to be done including developing a single common standardised EU trust model and certificate policy, and international cooperation on interoperability.

- **Governance of the system** – organisational principles to ensure interoperability (e.g. data management, data ownership and system reliability) remain poorly developed and there is strong disagreement between stakeholders – as highlighted by the C-ITS Platform final report – on access to data, ownership of those data, responsibility for running data services, etc.

- **Business models and implementation** – to avoid a fragmented approach to deployment and, hence, be better able to take advantage of network effects and the single market, national and regional business cases for the deployment of C-ITS need to be developed further. The role of incentives and other methods to foster deployment should also be further examined by the relevant authorities.

- **Public acceptance** – communication and education is needed to inform the public about the technological possibilities, benefits and contribution to societal goals to ensure acceptance and mitigate fears.

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9   http://ec.europa.eu/transport/themes/its/road/action_plan/
10   http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31995L0046:en:HTML

International cooperation – to maximise the potential of C-ITS in an increasingly global market, international cooperation will benefit industry and the public sector. There are agreements for cooperation between Europe, the USA and Japan. International cooperation activities are also supported by different European Commission Seventh Framework Programme (FP7) support action projects such as COMeSafety 2 and FOTNET, and the C-ITS Platform itself. Further work on international cooperation is recommended in the C-ITS Platform final report.

2.4 Research activities and outcomes

The research reviewed from TRIP has identified key research achievements across the various C-ITS sub-themes covering:

Defining common communications standards for different types of C-ITS messages – ETSI has defined two basic messaging services. These are the Cooperative Awareness Message (CAM) and the Decentralised Environmental Notification Message (DENM). CAMs are transmitted regularly by vehicles (one to ten times per second) and signal a vehicle's position, speed and direction. DENMs are transmitted to inform surrounding users about a specific event, such as a slippery road surface. DENMs are particularly relevant for safety applications. Signal Phase and Timing (SPaT) and Road Topology (MAP) messages have also been defined by CEN and the International Organization for Standardization (ISO). These are relevant for signalised intersections and are broadcast to inform vehicles about traffic light phase and timing or red light violations, and the local road topology, all of which can enhance safety and efficiency.

Finally, Probe Vehicle Data (PVD), Probe Data Management (PDM) and In-Vehicle Information (IVI) messaging standards have also been defined.

Efforts to ensure that the various communications technologies can be used to provide C-ITS services and that all relevant actors can cooperate within a common framework – various projects have tested the feasibility of delivering C-ITS services using a range of technologies including DSRC (through the ITS-G5 standard), cellular, satellite, and digital audio broadcasting (DAB) and frequency modulation (FM) radio. These services have been demonstrated successfully during a small trial and at a larger early deployment stage. In many cases, the trials identified the types of services that are suitable to be delivered via different communications technologies. Additionally, projects such as 'COmmunication Network VEhicle Road Global Extension' (CONVERGE, 2012) have developed cooperative architectures for V2X communications. These are intended to be flexible and open-access, and rely on information being shared between all relevant actors in the network (such as vehicle manufacturers, road authorities and fleet managers). Using this kind of cooperative architecture, each actor is responsible for providing information services and contributing to certain system functions, while network-level actors provide the communication services to enable C-ITS, and mobility-level actors exchange information about traffic and safety.

Developing various secure software solutions/architectures for use in C-ITS applications – various projects have investigated privacy-aware communication architectures and subsystems for V2V, V2I and V2X applications that enhance the level of security and data protection, and identify and address the various types of threats, attackers and vulnerabilities. The deliverables and other outcomes on the security requirements of vehicle systems, and specifications for secure software and architecture modules could be used by industry to develop data protection and security mechanisms for commercial products.

Advances in various fields related to freight transport and logistics – including platooning (the electronic coupling of two or more automated trucks driving in columns, where the technologies and sensors required have been developed to a near-commercial state through a variety of research and deployment projects), efficient driving and parking applications.

Developing optimised human-machine interaction (HMI) technologies – allowing a variety of assisted driving or warning systems to be incorporated in an increasing range of vehicles, while avoiding excessive driver distractions or 'information overload'.

Increasing deployment of various information systems for today's drivers – the dividing line between traffic management and mobility demand management is becoming blurred by technological developments and the emergence of information services targeted at individuals. More and more cooperative services are emerging.

- **Large-scale pre-commercial deployments of motorway-based C-ITS services** – building on earlier small-scale projects that have proved the viability of various C-ITS services, a number of large-scale projects are being deployed linking major TEN-T corridors across several European countries (such as SCOOP@F and the Cooperative ITS Corridor). As well as supporting the EU's objective of connecting European transport networks, these projects are setting the scene for the next stage, which is expected to be full commercial deployment of C-ITS services across many European motorways.

- **Developing a range of services to improve the experience of individual public transport users, and optimise the operation and functionalities of public transport systems** – various prototype applications and technological solutions have been developed to a point where the technological readiness level is high. This allows the methodologies developed and design parameters to be transferred to practical use, not only in similar local conditions but also in the wider European context.

- **Proven ability of various C-ITS services to provide beneficial impacts** – a wide range of C-ITS services have been field tested. It has been proved that they offer significant safety, efficiency and environmental benefits, thereby contributing to many of the European Commission's goals set out in the ITS Action Plan. The majority of these services have achieved high levels of user acceptance by users in the trials.

- **A wide variety of sensor technologies and data-handling mechanisms have been developed for C-ITS applications** – these range from in-vehicle dynamic sensors to hazard identification sensors and cover a range of technologies including cameras, radar, lasers, environmental monitoring sensors, strain gauges and biometric sensors. Sensor technology, data storage and data analytics have advanced as a result of many research projects. This has resulted in innovative combinations of sensor technologies being developed to solve complex problems in the transport sector.

- **Standardised software and hardware frameworks have been developed for C-ITS applications** – numerous projects have developed standardised software modules, guidance documentation or draft software/hardware standards that can easily be tailored to allow interoperable C-ITS to be developed across different EU markets and road types.

- **Proof of concepts for a range of urban C-ITS applications have been developed** – in particular, in the fields of traffic control, cooperative mobility services and urban traffic management, IT in electromobility and public transport, and route and personal planning.

Overall, this review of C-ITS research projects suggests that a lot of good technical research and early deployments in certain, more advanced, areas have been carried out. It also suggests that there is a significant body of research, best practice and standards available to take many C-ITS services to the next stage of commercial deployment. However, a number of areas have seen slower progress than others and several barriers have been identified that require continued attention. These include:

- Research to establish widely accepted data and privacy security protocols for use in C-ITS services and their underlying communications technologies.

- International coordination between the various parties is key to the deployment of C-ITS services, and is essential to increase the efficiency and learning capacity of researchers and market parties, to reduce the knowledge divide among European regions and to increase the competitiveness of the European transport sector as a whole. Initiatives such as the C-ITS Platform will be vital in helping to ensure this cooperation.

- Additional research on how to resolve the 'chicken and egg' problem on stimulating investment and on identifying viable business models in the sector – particularly at a more local or regional level where investment decisions will be made.

- Additional work on the standardisation of C-ITS services and the software/hardware frameworks on which they rely is necessary to ensure optimal cross-border and inter-city interoperability. Dealing with the standardisation issues is a necessary prerequisite for a successful and widespread market deployment in terms of:

  - complying with international standards and norms;

  - the use of open protocols and standardised software elements for ease of implementation and optimum interoperability.

- Integrating C-ITS service deployment plans into cities' long-term urban planning and transport regulation agendas. This will enable better and easier use of C-ITS services, and achieve maximum impacts by deploying newer and better services for travellers in the context of sustainable urban development.

- Improving the functional linkage of C-ITS applications as a core element of an integrated urban freight transport (UFT) scheme through increased cooperation between C-ITS and UFT projects.

Many of these issues are well aligned with the recommendations for additional work highlighted in the recent C-ITS Platform final report and continued efforts should be made to tackle them in a coordinated fashion.

2.5 Preliminary recommendations

Overall, the research on C-ITS is producing some important developments and results. These address many of the policy objectives in this area and support the move towards commercialisation of C-ITS services in the EU. In terms of taking C-ITS research forward, the following recommendations are made:

- **Communication technologies**

The technical and social factors that should be explored in future research include:

- an assessment of the performance of next generation communication technologies, their applicability to connected transport applications and the costs associated with their use;

- the development of relevant standards as communication technologies advance to ensure a consistent approach across Europe and maintain interoperability;

- an investigation into the security and privacy/data protection challenges associated with the use of different communication technologies;

- research into technical factors (such as the latency and reliability of communication technologies and improvements to them) especially where there are high levels of deployment of C-ITS services in congested areas.

- **Data protection and security**

Further research is required to establish common methodologies, data protocols and standards for addressing issues of data protection and security among C-ITS services and their supporting technologies, including:

- developing privacy metrics to quantify and compare levels of protection provided by different policies and security systems;

- developing privacy requirements and standards in the context of data collection activities (using alternative instruments such as mobile device applications, travel surveys, automated licence plate readers, smartcard readers, etc.);

- large sample 'big data' analysis on a pan-European level that will allow comparisons of user awareness and expectations regarding data sharing, privacy and security issues, and adoption rates of ITS-related platforms and systems across EU countries.

- **Freight transport and logistics**

The requirements for research in this area include:

- investigate how to ensure the interoperability of sensors with a wide range of C-ITS services and advanced driver assistance systems to allow increasingly complex services to be deployed that rely on information generated by a multitude of sensors;

- investigate the potential for integrating applications in the V2I domain in systems that can be offered as a service for managing freight transport infrastructures;

- investigate commercial business models and integrated frameworks for linking connected vehicles to open and connected infrastructures that involve public and private infrastructures through 'collaborative logistics'.

- **Human-machine interaction**

The priorities for research in this area include:

- HMI to inform drivers of non-safety related traffic characteristics, such as congestion mitigation or fuel efficiency;

- the development of integrated vehicle and HMI concepts for all types of users, including the elderly and disabled;

- the requirements for data and privacy security of HMI interfaces, with particular reference to the potential presence of fully automated vehicles in the future.

- **Information systems/platform**

The priority for research in this area include:

- the development of systems capable of gathering, processing and enriching big data in real time, and covering a mix of different information channels such as navigation systems, smartphones, infrastructure and in-vehicle devices.

- **Motorway applications**

The requirements for research in this area include:

- investigate the application of C-ITS motorway services to other vehicle types (such as freight), focusing on improvements to non-safety aspects (such as congestion and fuel efficiency);

- quantify the wider costs and benefits of the C-ITS motorway applications under development to ensure they can deliver benefits in a cost-effective manner;

- a greater emphasis on the publication and sharing of the main research outputs;

- investigate the user acceptance of C-ITS under motorway conditions and determine improvements to the systems (including the HMI interface) to increase acceptance.

- **Public transport**

The key aspects of research in this area include:

- the integration of C-ITS and innovative transport services (such as car-sharing and automated bus services) with the core public transport network – in particular, the ability to solve the 'first kilometre, last kilometre[11]' problem;

- the role of C-ITS in the integration of automation into the public transport system;

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[11] The extra time and difficulty experienced when travelling from home to a public transport access point and towards the end of a journey from the public transport access point to the final destination

- the development of multimodal travel planners using big data and advanced predictive analytics;

- the development of Mobility as a Service (MaaS) systems for providing integrated travel and payment services to travellers.

• **Safety, efficiency and emissions**

The priorities for research in this area include:

- conducting in-depth analyses of the links between the intelligent vehicle systems and improvements in driver behaviour, fuel efficiency, traffic safety and overall cost savings;

- investigating the risks to traffic safety related to the reliability of the C-ITS infrastructure – in particular, how to overcome any potential collapse of the systems;

- investigating the risks related to internet attacks (viruses and hackers) on the safety and security of the transport system;

- the development of guidance for policy makers and transport engineers on how to plan and invest in appropriate C-ITS to save energy, reduce emissions and increase safety; to clarify the market for specific ITS applications; and to understand the barriers to implementation.

• **Sensors**

The priorities for research in this area include:

- investigate how the interoperability of different sensors can be achieved to provide efficient data fusion capabilities;

- integrating sensing systems developed for advanced driver assistance systems (ADAS) applications with the communication technologies in C-ITS;

- developing advanced sensors and the use of the data provided by them for non-safety-related benefits (such as fuel efficiency and emissions) and for a greater variety of vehicle types (beyond passenger cars).

• **Urban applications**

The priorities for research in this include:

– developing urban C-ITS services to a similar level of maturity as motorway services to help overcome the various transport-related issues affecting cities in the EU;

– investigating integration issues between C-ITS services and urban transport, including emerging technologies and trends (such as integrated public transport and sharing services, multimodal mobility, MaaS, crowdsourcing and iBeacon™ technologies);

– investigating the application of big data collection and analysis activities to support the future of urban mobility (such as dynamic measurements via smartphones, visualisations and analyses using large-scale data, and market demand analyses for public mass transportation);

– investigating the processes and traffic flow mechanisms within an urban environment related to the:

> influence on traffic capacity (smoothing the flow);

> reliability of the systems under different traffic conditions;

> adaptation to and interaction with the traffic environment;

> effects of coupling between different systems;

> safety (looking at the driver behaviour and traffic processes and developing a long-term database of incidents);

> user acceptance and understanding of new technologies.

2.6 Comparison with outcomes from C-ITS Platform report

Many of the recommendations drawn from the review of research activities and outcomes, outlined in Section 2.5 above, are consistent with the conclusions and recommendations from the C-ITS Platform final report (see Section 2.2.2 for further details).

In particular, the following common themes from the C-ITS Platform final report are also picked up in the recommendations outlined above from this analysis:

• **Communication technologies**

– Further develop the hybrid communications concept and define communications standards and security protocols which are independent of particular technologies to ensure that C-ITS services can be deployed using a range of technologies, including those that may become relevant in the future. This was highlighted in the recommendations from Working Groups 1, 6 and 9.

– Establish, in greater detail, the capabilities of cellular communications for the delivery of C-ITS services, particularly in relation to safety-critical services (e.g. latency times and performance in congested areas). This theme was picked up mainly in recommendations from Working Groups 6 and 9.

– Evaluate the costs and business models for the deployment of hybrid communications concepts. This was highlighted in the recommendations from Working Group 1.

• **Data protection and security**

– Define an EU-wide trust model and common security certificates to work across all C-ITS services and supporting communication technologies. This was recommended by Working Group 5 in particular.

– Define categories for levels of protection provided to personal data and different consent levels, based, for example, on whether the messages are vital safety services, in the public interest or for providing value-added services. This was recommended by Working Group 4 in particular.

• **Freight transport and logistics applications**

– Further investigate the interaction between equipped and non-equipped vehicles, and options for integrating with legacy infrastructure to provide a broader range of C-ITS services aimed at different markets. This was recommended by Working Group 9 in particular.

– Clearly define business models for the deployment of C-ITS services. This was recommended by Working Groups 1 and 2.

• **Human-machine interactions**

– Revise the European Statement of Principle on HMI to take into account of the impacts of deploying C-ITS. This was recommended by Working Group 9.

• **Information systems/platform**

– Better understand the form and capabilities of back-office systems and their underlying business models. This was recommended by Working Group 1 in particular.

• **Motorway applications**

– Establish the performance, costs and business models of C-ITS services in vehicles other than passenger cars. This was recommended by Working Group 1.

– Engage closely with all the key stakeholders involved in C-ITS deployment to ensure a smooth process towards commercialisation of C-ITS services. This was recommended by Working Groups 1 and 8.

– Establish more local/regional or stakeholder-specific business models to support investment decision-making in the deployment of C-ITS. This was recommended by Working Groups 1 and 9.

- **Public transport applications**

  - Further investigate the interaction between equipped vehicles and existing/planned infrastructure to provide a more integrated set of C-ITS services. This was recommended by Working Group 9 in particular.

  - Further research into urban-focused services to better establish their capabilities, costs and business models. This was recommended by Working Groups 1 and 9.

- **Safety, efficiency and emissions**

  - Develop inherently safe and resilient security standards that protect the privacy of individuals using C-ITS services, develop a revocation of trust framework for C-ITS messages and ensure a flexible approach to securing communications that can be altered to include new cryptographic algorithms as and when needed. This was recommended by Working Group 5 in particular.

  - Engage with a wide range of stakeholders to encourage acceptance and clarify the business case to likely investors to ensure that they have all the knowledge at their disposal to make investment decisions. This was recommended by Working Groups 1, 8 and 9.

- **Sensors**

  - Further investigate options for integrating with existing sensors and equipment to provide a broader range of C-ITS services aimed at different markets. This was recommended by Working Group 9 in particular.

  - Develop C-ITS services aimed at segments other than passenger cars. This was recommended by Working Group 1 in particular.

- **Urban applications**

  - Additional focus on developing urban applications for C-ITS services. This was recommended by Working Group 1 in particular.

- Further investigate the interaction between equipped vehicles and existing/planned infrastructure to provide a more integrated set of C-ITS services. This was recommended by Working Group 9 in particular.

There were significant overlaps between the C-ITS Platform final report recommendations and some of the recommendations from this analysis of the research environment and its outcomes. However, a number of specific areas for further work are highlighted in the C-ITS Platform final report that were not identified in the current review of the research environment. These recommendations include:

- Develop in-vehicle and back-office equipment and infrastructure that is service-independent and able to support any C-ITS service from any number of service providers.

- Work to consolidate the different radio equipment that is required on vehicles to reduce the overall cost of providing multiple radio-frequency communications systems.

- Carry out further work to better understand what form aftermarket devices are likely to take, their likely capabilities, costs and their impacts on standardisation efforts.

- Develop a code of conduct for privacy-related issues for those designing and deploying C-ITS services.

- Set up a legislative framework by detailed consultation with relevant stakeholders to provide legal certainty on privacy and security issues and identify the financing mechanism for these efforts.

- Carry out an analysis on the legal, liability, technical and cost-benefit aspects of access to in-vehicle data where a significant amount of work remains to be done to ensure that all the relevant stakeholders agree to a common set of standards and legislation. In particular, work is required to standardise in-vehicle interfaces and on-board applications to develop an advanced physical/electrical/logical interface, which includes the necessary minimum level of security, minimum datasets and standardised data protocols to enable C-ITS services.

3 Sub-theme assessments

3.1 Communication technologies

3.1.1 Preliminary recommendations

Research into communications technologies that are suitable for Cooperative Intelligent Systems (C-ITS) underpins many other research activities in the C-ITS theme – without reliable, secure, trustworthy and interoperable communications, C-ITS simply would not be able to function effectively. The direction of communication technology research is closely linked to the outcomes of research in other sub-themes, such as data protection, and security and information systems/platform. These research areas explore some of the wider challenges for widespread deployment of C-ITS and provide guidance on the goals of future research in communication technologies.

To achieve a swift and successful deployment of C-ITS throughout Europe, it is generally agreed that a hybrid communication technologies approach will initially be adopted (ERTICO, 2015). This means that different communication technologies will be used depending on the application or the location of the vehicle. This approach will allow the strengths of existing communication technologies to be used while emerging technologies are refined. For example, cellular networks offer very high geographical coverage throughout Europe and could be used to provide traffic information services. However, short-range communication technologies, such as ITS-G5, have lower coverage, but are capable of a lower latency (reduced communication delays). This is an important requirement for safety services that rely on the fast transfer of information relating to upcoming road hazards.

Furthermore, for ITS-G5 technology, there is the potential for multi-channel and multi-antenna use. This could allow safety critical messages to be sent and received via a separate channel, for example.

The technical and social factors that should be explored in future research relating to communication technologies include:

• Assessing the performance of next-generation communication technologies, their applicability to connected transport applications and the costs associated with their use.

• Defining relevant standards as communication technologies develop to ensure a consistent approach across Europe and maintain interoperability.

• Considering security and privacy/data protection challenges associated with the use of different communication technologies.

• Conducting research into technical factors, such as the latency and reliability of communication technologies, especially where there are high levels of deployment of C-ITS services in congested areas.

• As communication technologies are still rapidly developing, ensure that new generations of technology are compatible with the previous generations (backward compatibility) so that early adopters are not disadvantaged and deployment costs can be minimised. Similarly, forward compatibility should be taken into consideration to ensure that systems will be compatible with new technology developments.

3.1.2 Research environment and development

A total of 59 research projects were identified under the communication technologies sub-theme. Of these, 18 were classified as having 'short profiles' so were used in the analysis only to identify the total scope of research being performed (mainly through their titles) and were not analysed in detail. The other projects were analysed to understand the research direction, technology status and results obtained in the area of communication technologies.

Of the 59 projects identified, 26 were financed by various European programmes, while 33 were funded by national programmes. Table 3-1 summarises the projects included in this analysis, their duration and source of funding. The table does not include the 'short profile' projects. A similar approach has been adopted for the other sub-theme assessments described in this report.

Table 3-1 Projects identified for the accessibility sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	To optimise traffic safety and traffic flow in the winter by using modern communication technology in highway operation. Original language title: Optimierung der Verkehrssicherheit und des Verkehrsflusses im Winter durch den Einsatz moderner Kommunikationstechnologie im Strassenbetrieb	2005-2008	National (Switzerland) ARAMIS – ARAMIS information system
N/A	ITS towards 2020 Original language title: ITS på veg mot 2020	2007-2010	National (Norway) Vegvesen/NPRA – Norwegian Public Roads Administration (various projects)
N/A	Future applications in satellites navigation for road telematics and for road management system. (VSS2003/903) Original language title: Perspectives et applications des méthodes de navigation par satellites pour la télématique des transports routiers et pour le système d'information de la route	2005-2010	National (Switzerland) ARAMIS – ARAMIS information system
N/A	Promotion of the use of Advanced Telecommunications Services in the Transport Sector Original language title: Promoción del uso de los Servicios Avanzados de Telecomunicaciones en el Sector del Transporte	2005	National (Spain) ARTE/PYME II – Regional Actions in Telecommunications for Small and Medium-sized Enterprises (SMEs)
N/A	Development of an Integrated Management System for Transport based on GSM Original language title: Desarrollo de un Sistema de Gestión Integrado del Transporte basado en GSM	2005	National (Spain) ARTE/PYME II – Regional Actions in Telecommunications for Small and Medium-sized Enterprises (SMEs)
79GHZ	International automotive 79 GHz frequency harmonization initiative and worldwide operating vehicular radar frequency standardization platform	2011-2014	FP7-ICT – Information and Communication Technologies
CENTRICO	Central European Region Transport Telematics Implementation Project	2001-2006	FP7-ICT – Information and Communication Technologies
CoCarX	CoCarX	-	National (Germany)
COM2REACT	Cooperative Communication System to Realise Enhanced Safety and Efficiency in European Road Transport	2006-2007	FP6- IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
COMPOSE	Composition Of Mobile Pre-trip On-trip Services	2002-2004	FP5-IST – KA1 – Systems and services for the citizens

Table 3-1 (continued) Projects identified for the accessibility sub-theme

Project acronym	Project name	Project duration	Source of funding
COMOSEF	Co-operative Mobility Services of the Future	–	
CONVERGE	COmmunication Network VEhicle Road Global Extension	2012-2015	National (Germany)
COOPERS	Co-operative Networks for Intelligent Road Safety	2006-2010	FP6 -IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
CVIS	Cooperative Vehicle-Infrastructure Systems	2006-2010	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
DIAMOND	Delivery of ITS Applications through Multimedia Over Networks Using DAB	2000-2001	FP5-IST – KA1 – Systems and services for the citizens
DUPLO	Universal device for payment, localisation and operational activities Original language title: Dispositivo Universal de Peaje, Localización y Operación	2002-2004	National (Spain) PROFIT 01 – National Programme of Transport and Land Use
ECOGEM	Cooperative Advanced Driver Assistance System for Green Cars	2010-2013	FP7-ICT – Information and Communication Technologies
FOKAT	Conditions and requirements on IT support for demand-responsive public transport Original language title: Förutsättningar för och krav på IT-stöd för anropsstyrd trafik	2003-2006	National (Sweden) VINNOVA – VINNOVA Transport Programme
FOTSIS	European Field Operational Test on Safe, Intelligent and Sustainable Road Operation	2011-2014	FP7-ICT – Information and Communication Technologies
GAUSS	Galileo[12] and UMTS Synergetic System	2000-2002	FP5-IST – KA1 – Systems and services for the citizens
GAWAIN	Galileo W-CDMA Integrated Navigation	2002-2005	FP5-IST – KA1 – Systems and services for the citizens
GEMINUS	Galileo European Multimodal Integrated Navigation User Service – Galileo Service Definition	1999-2001	FP5-GROWTH – KA2 – Sustainable Mobility and Intermodality
HIGHWAY	Breakthrough Intelligent Maps and Geographic Tools for the Context-aware Delivery of E-safety and Added-value Services	2004-2006	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
ITSWAP	Intelligent Transport Services over Wireless Application Protocol	2000-2001	FP5-IST – KA1 – Systems and services for the citizens
MISS	Monitor Integrated Safety System	2004-2007	FP6-SUSTDEV – Sustainable Development, Global Change and Ecosystems – Priority Thematic Area 6 (PTA6)
MNS	System for advanced monitoring of the means of transport and freight mobility in multimodal transport – Multimodal Network System Original language title: Sistem de monitorizare avansată a mobilității mijloacelor de transport şi mărfurilor multimodal – suport pentru realizarea societății naționale informaționale mobile	2002-2004	National (Romania) AMTRANS – Territory Arrangement and Transport

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[12] The Galileo programme is Europe's initiative for a state-of-the-art global satellite navigation system, providing a highly accurate global positioning service under civilian control.

Table 3-1 (continued) Projects identified for the accessibility sub-theme

Project acronym	Project name	Project duration	Source of funding
MOBIEUROPE	Integrated and Interoperable ICT Applications for Electro-Mobility in Europe	2012-2014	European – The Information and Communication Technologies Policy Support Programme
MOBINCITY	SMART MOBILITY IN SMART CITY	2012-2015	FP7–ICT – Information and Communication Technologies
MOBITRAFF	Cooperative Way to Mobility and Traffic Efficiency	2013-2014	
NIV	Network Traffic Equalizer Original language title: Netzausgleich Individualverkehr	2001-2005	National (Germany)
NordicWay	NordicWay	-	National and European Connecting Europe Facility (CEF)
PROBEIT	Foresight Vehicle	2000-2003	National (UK) DfT HE – Department for Transport – Highways England (various projects)
REPOSIT	Relative Positioning for Collision Avoidance Systems	2006-2007	FP6–IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
SAFETRIP	Satellite application for emergency handling, traffic alerts, road safety and incident prevention	2009-2013	FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)
SALICE	Systems of location and communication assisted by satellite for emergency services Original language title: Sistemi di localizzazione e comunicazione assistiti dal satellite per servizi di emergenza	2008-2010	National (Italy) PRIN calls 2006 and 2007 – Research projects of national relevance calls 2006 and 2007
SCOOP@F	Système Coopératif Pilote @ France	2014-2018	National (France)
SERTI	Southern European Road Telematics Implementation	1997-2006	European MIP – MAP – Multi-annual Indicative Programme (MIP), Multi Annual Programme (MAP)
SIMBAD	Innovative System of Bidirectional Communications for moving vehicles Original language title: Sistema Innovador de comunicaciones Bidireccionales por satélite para vehículos con movilidad	2007-2009	National (Spain) PROFIT – Programme for the promotion of technological research
SimTD	Safe Intelligent Mobility Test Field Germany Original language title: Sichere Intelligente Mobilitat Testfield Deutschland	2008-2014	National (Germany)
VMTL	Traffic Management in Transport and Logistics Original language title: Verkehrsmanagement in Transport und Logistik	2001-2005	National (Germany)
WATCH-OVER	Vehicle-to-Vulnerable Road User Cooperative Communication and Sensing Technologies to Improve Transport Safety	2006-2008	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)

3.1.2.1 Overall direction of research

For C-ITS services to work effectively, a frequent exchange of information is required between vehicles, personal devices and the road infrastructure, covering data such as vehicle speed, position, direction of travel and real-time travel information/advice. The Day 1 C-ITS services envisaged for initial deployment within the EU are not linked to specific communication technologies (Amsterdam Group, 2014). However, some communication technologies may be more suitable for some services than others. Analysis of projects within this sub-theme revealed that a variety of communication technologies have been explored, including:

- radio (frequency modulation/digital audio broadcasting (FM/DAB));

- cellular networks (2G, 3G, and 4G);

- short range communication technology (ITS-G5);

- satellite (global positioning system (GPS)).

To understand which communication technologies are the most appropriate for different C-ITS services, it is necessary to appreciate the performance characteristics required to deliver these applications. For example, factors such as the data transfer rate and whether bidirectional communication is required need to be considered. Projects researching the technologies listed above are discussed in further detail in Section 3.1.3.1.

Progress has also been made in the standardisation of messages used in C-ITS communications, including Cooperative Awareness Message (CAM), Decentralized Environmental Notification Message (DENM), Signal Phase and Time (SPaT) and Road topology (MAP), Probe Vehicle Data (PVD), Probe Data Management (PDM) and In-Vehicle Information (IVI). These message types and relevant projects are discussed in further detail in Section 3.1.3.1.

3.1.2.2 Trends, knowledge gaps and policy requirements

Analyses of projects under the communication technologies sub-theme revealed how research trends have changed over time. More recent projects (such as 'Système Coopératif Pilote @ France' (SCOOP@F, 2014-2018), NordicWay and 'Integrated and Interoperable ICT Applications for Electro-Mobility in Europe' (MOBIEUROPE, 2012-2014) have tended to focus on using cellular and short-range communication technologies for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) interactions. Previously, the use of satellite (GPS) received a lot of attention exemplified by projects such as:

- 'Satellite application for emergency handling, traffic alerts, road safety and incident prevention' (SAFETRIP, 2009-2013);

- 'Systems of location and communication assisted by satellite for emergency services' (SALICE, 2008-2010);

- 'Galileo W-CDMA Integrated Navigation' (GAWAIN, 2002-2010);

- 'Galileo and UMTS Synergetic System' (GAUSS, 2000-2002);

- 'Galileo European Multimodal Integrated Navigation User Service – Galileo Service Definition' (GEMINUS, 1999-2001).

There is also a trend towards the increased use of communication technologies to create more sustainable transport options and to increase public awareness of those options in smart cities. Several projects investigated how communication technologies can be used to connect electric vehicles (EVs) to infrastructure such as charging stations and traffic management systems. As shown by the 'Cooperative Advanced Driver Assistance System for Green Cars' (EcoGem, 2010-2013) and 'SMART MOBILITY IN SMART CITY' (MOBINCITY, 2012-2015) projects, research is also ongoing to equip EVs with a greater range of infotainment services, advanced driver assistance systems (ADAS) and adaptive route guidance, all of which rely on communication technologies. Smartphone apps have also been developed during projects to connect users to transport services within their city. For example, the MOBINCITY app developed for Valencia and Ljubljana allowed users to book parking spaces; and EV charging stations had route planning capability via a number of modes including bike, bus, EV sharing, user EV, foot, tram and underground. Ultimately, developments in this area should deliver environmental, safety and efficiency/time-saving benefits, and lead to a more comfortable transport experience.

3.1.2.3 Fit with current policy and targets

Communication technologies are at the centre of much of the research into C-ITS. As such, they enable many of the priority areas stated in the ITS Directive (EU, 2010) to be addressed by research in other sub-themes. Therefore, research in this area aims to test the applicability of the latest communication technologies in the transport sector.

The projects in this sub-theme focus on priority research areas targeted by recent EU research and innovation funding programmes such as the European Commission's Seventh Framework Programme (FP7). For example, many of the projects were funded under the Information and Communication Technologies activity area of FP7 (FP7–ICT), where a key objective was to have an impact on the modernisation of public services such as transport. More specifically, the ICT Work Programme was divided into eight challenge areas. Of most relevance to communication technologies was 'ICT Challenge 6: ICT for a low carbon economy', which contains a specific objective (ICT-2011.6.7) focused on C-ITS for energy efficient and sustainable mobility (EC, 2013).

3.1.2.4 Overlaps and synergies within the European research community

Rather than developing and improving the underlying communication technologies, most projects within this sub-theme tested the suitability of communication technologies for different C-ITS services. A number of projects also investigated how communication technologies can be integrated with existing traffic management or in-vehicle platforms. Therefore, a large overlap between projects is noticeable, which highlights the importance of sharing project outcomes and best practice within the European research community.

Synergies are also evident in terms of the applications tested. For example, the 'Cooperative Way to Mobility and Traffic Efficiency' (MOBITRAFF, 2013-2014) concept uses vehicular ad-hoc networks for traffic management and builds on ideas tested during the 'Cooperative Vehicle-Infrastructure Systems' (CVIS, 2006-2010) project. In the future, it will be vital to assess the performance of C-ITS services using different communication technologies to ensure that the most useful and cost-effective system is chosen for deployment.

3.1.3 Research activities and outcomes

3.1.3.1 Technology status

As discussed in Section 3.1.1, a number of communication technologies have been used in C-ITS research projects. Table 3-2 shows a selection of projects, communication technologies and their applications.

As communication technologies have advanced, standardisation activities have taken place. The European Telecommunications Standards Institute (ETSI) has defined two basic messaging services – CAM and DENM. CAMs are regularly transmitted by vehicles (one to ten times per second) and signal a vehicle's position, speed and direction. DENMs are transmitted to inform surrounding users about a specific event, such as a slippery road surface. DENMs are particularly relevant for safety applications.

SPAT and MAP messages have also been defined by the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO). These are relevant for signalised intersections and are broadcast to inform vehicles about traffic-light phase and timing or red-light violations, which can enhance safety and efficiency. SPAT and MAP messages could be transmitted by ITS-G5 or cellular, depending on the latency required.

Understanding how communication technologies, vehicles and infrastructure fit together and can most efficiently interact within the transport system is another area addressed by projects in this sub-theme. The 'COmmunication Network VEhicle Road Global Extension' project (CONVERGE, 2012-2015) has made significant progress by developing a cooperative architecture for vehicle-to-everything (V2X) communication. This architecture was designed to ensure that the time between information acquisition and information use is significantly reduced. Consequently, road users will be able to receive valuable information almost in real time and have the opportunity to decide on the best course of action.

The CONVERGE architecture is intended to be flexible and open access, and relies on sharing information between different actors in the network. The concept of actors is seen to be central to CONVERGE. These include backend/backbone level actors, such as vehicle manufacturers, road authorities or fleet managers, are responsible for providing information services and contribute towards certain system functions. Network-level actors then provide the communication services to enable C-ITS. Finally, mobility level actors exchange traffic and safety-related information. Systems such as CONVERGE have the potential to bring together stakeholders involved in the deployment of C-ITS and accelerate the uptake of technology within Europe.

Table 3-2 Communication technologies trialled in European research projects

Technology	Example project and application(s)
FM/DAB radio	DIAMOND: investigated the feasibility of using DAB, cellular (Global System for Mobile Communication (GSM™)) and positioning systems (GPS) to deliver multimedia ITS services to users. This resulted in some standardisation activities in the field.
Satellite (GPS)	GAUSS: demonstrated how location-based services (for freight and fleet management, road safety and info-mobility, emergency assistance, dangerous goods transportation control and inter-modal transport) based on Galileo (satellite navigation) and Universal Mobile Telecommunications System (UMTS) (cellular) technology can be used to improve mobility.
Cellular	NordicWay: will be the first large-scale pilot (up to 2 000 vehicles) using cellular communication (3G and LTE/4G) for C-ITS. Core services to be trialled are cooperative hazardous location warning, cooperative weather and slippery road warning, and probe data services.
Short-range communication such as ITS-G5 (vehicular Wi-Fi) – this operates in the 5.9 GHz band and is defined by IEEE 802.11p	simTD: this project built the first 'vehicle to X' (V2X) communication cooperative traffic control centre. The project involved 500 participants and 120 vehicles with a total of 41,000 hours and 1.65 million kilometres of testing. The field operational tests (FOT) demonstrated network-level latency times of less than 15 ms, which are crucial for safety applications. The C-ITS Deployment Corridor NL-DE-AT project followed on after the achievements in this project.

3.1.3.2 Transferability from research to practical use

As with other sub-themes, projects in this area often build on each other, which helps to accelerate the research process. More experience of trialling communication technologies in real-world driving situations will contribute towards European competitiveness in this area and provide ideas for future research. Furthermore, the development of appropriate standards should pave the way for the practical use of communication technologies in C-ITS.

3.1.3.3 Policy implications

The rapidly developing nature of C-ITS communication technologies means that policies applicable to this area will need to be monitored to ensure they are relevant for the state-of-the-art technologies being deployed. Progress is ongoing in the definition of standards relevant to communication technologies and this is expected to continue as C-ITS services mature. Research projects in this area highlighted the importance of involving stakeholders throughout the development process to ensure a more efficient deployment of C-ITS throughout Europe.

3.2 Data protection and security

3.2.1 Preliminary recommendations

Travellers generate massive quantities of detailed information (individual, activity, travel and location) through a variety of channels (such as payments, subscriptions, social media, mobile apps, internet cookies). This increases the exposure and possibility of inappropriate use of individual information, which raises significant concerns on data privacy, protection and security. Data protection, privacy and security are requirements of most ITS projects. However, so far, most projects have addressed these issues in an ad-hoc/proof-of-concept manner resulting in a limited understanding of the core issues which need to be addressed across Europe.

Further analysis is required to assist in defining common methodologies that address issues of data protection and security among transport projects. Thus, future research should be focused on the development of:

• privacy metrics to quantify and compare levels of protection provided by different policies and security systems;

• privacy requirements and standards for data collection activities (using alternative instruments such as mobile device applications, travel surveys, ANPR equipment, smartcard readers);

• protocols for collecting, storing, sharing and using transportation and location data with consistent data protection and security principles;

• policy and technical methodologies to address data collection and security issues relating to autonomous and connected vehicles;

• large-sample, big-data analysis on a pan-European level that will allow comparisons of user awareness and expectations regarding data sharing, privacy and security issues, and adoption rates of ITS-related platforms and systems across EU countries.

3.2.2 Research environment and development

All research actions under this sub-theme are closely related to and confined by data protection issues. Apart from one project that aimed to review and gather information on different aspects of privacy in road safety, the main two objectives of the research performed under data protection and security are to:

• provide, update and/or modify security specifications and guidelines for the development of C-ITS;

• develop innovative applications and security subsystems for V2V, V2I and V2X communication.

The common underlying principle in these research projects relates to the existing data protection regulations and security issues with regard to sensitive user data, and avoidance of abuse and privacy violations.

3.2.2.1 Trends, knowledge gaps and policy requirements

Although the number of projects available in this sub-theme is limited, the main common trend identified is the development of technological platforms and technical specifications of system architecture and security mechanisms to provide the required level of data protection regarding on-board architecture and on-board communications. With the exception of the 'Preparing Secure Vehicle-to-X Communication Systems' project (PRESERVE, 2011-2014) all other projects started in the last decade and finished by 2011. Research is required to design robust C-ITS security systems for protection against internal and external threats to their primary elements – communications, devices, network (including associated systems such as GPS) and organisational structure. The increasing use of data storage in the 'cloud' may bring new threats to data security; future research should take account of such approaches to data storage. On the other hand, with transport-related privacy regulations still evolving and ITS becoming increasingly reliant on travellers' personal data and real-time information, further research on this topic is required. This research should aim to fill in gaps related to policy requirements that focus more on the fragmented privacy regulations and the need to establish the necessary regulatory framework conditions through standardisation or regulation for innovative transport, as set out in the European Commission's 2011 Transport White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system' (EC, 2011).

3.2.2.2 Fit with current policy and targets

The projects reviewed under data protection and security primarily address one of the three main reinforcing priorities of the European 2020 Strategy – smart growth (fostering knowledge, innovation, education and digital society) (EC, 2010). Moreover, the general theme, specific objectives and results produced by all six research projects analysed under this sub-theme (see Table 3-3) fit, to a large extent, with the wider current EU policies on data protection and security. All projects answer directly to the stipulation of the 2011 Transport White Paper with regard to the thematic priority 'Innovating for the future – technology and behaviour' and, more specifically, the need for measures to protect privacy and personal data to be developed in parallel with the wider use of information technology tools. However, the projects are directed, to a lesser extent, towards defining conditions for access to transport data, for safety and security purposes, that would contribute to establishing a regulatory framework for innovative transport – another related target of the 2011 Transport White Paper.

Regarding the communication from the European Commission 'Action Plan for the Deployment of Intelligent Transport Systems in Europe' (EC, 2008) and its associated 'Directive 2010/40/EU' (EC, 2010b) Area 5 (in line also with the Digital Agenda for Europe), the majority of projects address security and data protection issues, while only CVIS and 'SEcure VEhicle

COMmunication' (SEVECOM, 2006-2008) address liability issues. These liability issues are set out in the Action Plan, particularly for in-vehicle safety systems.

3.2.2.3 Overlaps and synergies within European research community

The privacy guidelines and architectures developed by research actions in this sub-theme could be adopted in an integrated methodology for the development of secure applications and systems. The results of the research could enhance the basis for amendments and changes in data protection and security regulations followed across the EU research community. In addition, the transferable and scalable elements of the specific applications and technologies developed through these actions may be exploited in future research projects, but only for relevant communication systems (V2V, V2I, V2X).

3.2.3 Research activities and outcomes

A total of six projects were reviewed under the data protection and security sub theme. One of these projects was nationally funded (by Norway), the remainder were EU-funded under the FP6 or FP7 programmes. The projects are listed in Table 3-3.

3.2.3.1 Status of the technology

In general, the research projects contributed to information and communications technology (ICT) research and application in cooperative systems by focusing on various areas of functionalities, data protection and security. They investigated privacy-aware communication architectures and subsystems for V2V, V2I and V2X applications that enhance the level of security and data protection, and identified and addressed the various types of threats, attackers and vulnerabilities. The deliverables and other outcomes on the security requirements of vehicle systems and specifications for architecture modules could form helpful bases for future initiatives on developing and/or upgrading current data protection and security mechanisms.

3.2.3.2 Transferability from research to practical use

The nature of the projects of this sub-theme favours the transferability of their results to practice. Accordingly, a number of projects have designed and developed software and/or secure architecture specification and protocols for uptake by industry. CVIS developed a technology platform providing wide-ranging functionality for data collection, journey support, traffic and transport operations, and driver information. The 'E-safety Vehicle Intrusion proTected Applications' (EVITA, 2008-2011) project developed cost-efficient hardware security modules (HSM) to help several embedded applications to efficiently improve their security. The 'Privacy Enabled Capability In CO-operative systems and Safety Applications' project (PRECIOSA, 2008-2010) created models to be used in V2V and V2I applications and designed an architecture that can guarantee certain privacy properties, which can be verified by some external partner (such as a user or trusted third party). Finally, the PRESERVE project designed, implemented and tested a secure and scalable V2X security subsystem for realistic deployment scenarios.

3.2.3.3 Implications of the research results for future policy development

Several research projects have designed privacy enhancement technologies and security mechanisms for application to C-ITS which comply with privacy and data protection regulations. The approaches developed could be exploited in future policy development for setting up codes of practice to ensure adequate compliance with the privacy regulations, and the management and verification of privacy policy.

Table 3-3 Projects reviewed under the data protection and security sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	Data Protection and Privacy Implication in Road Safety	2008-2010	National (Norway)
CVIS	Cooperative Vehicle-Infrastructure Systems	2006-2010	FP6
EVITA	E-safety Vehicle Intrusion proTected Applications	2008-2011	FP7
PRECIOSA	Privacy Enabled Capability In CO-operative systems and Safety Applications	2008-2010	FP7
PRESERVE	Preparing Secure Vehicle-to-X Communication Systems	2011-2014	FP7
SEVECOM	SEcure VEhicle COMmunication	2006-2008	FP6

3.3 Freight transport and logistics

3.3.1 Preliminary recommendations

C-ITS has been widely developed and tested in the freight transport and logistics domain. The possibility to exchange data in real time between freight vehicles and between vehicles and infrastructure has significant impacts, especially on the operational aspects and on the overall efficiency of the entire supply chain.

Typically, the freight transport domain is characterised by an integrated system of vehicles (e.g. trucks, vans, ships and trains) and equipment (e.g. cranes, weigh stations, fork-lift trucks and trailers) relying on efficient and punctual infrastructures, such as hubs or loading/unloading bays, for its operation. By its nature, this transport system provided ideal opportunities for advancing research and market development of C-ITS applications, which have been largely demonstrated through the assessments of the research projects (including the ones not directly analysed in this section (e.g. CVIS)).

The majority of projects identified for this sub-theme were funded by the EU, with only a few nationally-funded projects. However, the projects are, in general, characterised by large partnerships involving research institutions and industry actors, ranging from small to medium sized enterprises (SMEs) to large companies, and information technology manufacturers. Projects are large in terms of budgeted resources and typically carried out with field operational tests (FOTs) and pilot activities.

Analyses of research projects indicated that V2V solutions are, in general, well researched and tested with direct impacts on the market and the functioning of the entire supply chain. Research on V2V has also demonstrated more tangible improvements in safety and environmental impacts. However, in the V2I domain, the technologies that have been developed, although tested and validated, are still to be integrated in the real-life infrastructure management to be able to be offered as service.

Research on C-ITS for freight transport and logistics should invest more in generating business models and integrated frameworks for linking already-connected vehicles to open and connected infrastructures. This aspect involves private infrastructures (e.g. the possibility of dynamically sharing data and unused warehouse capacity) and is linked to the wider concept of collaborative logistics. It also includes public infrastructures where the level of commercial deployment is still relatively low especially at urban level (e.g. providing priority for freight vehicles at traffic lights, use of bus lanes, parking slots and access to certain zones linked to more dynamic elements such as intelligent routing and load factor detection). Open data and availability of updated and accurate digital maps of network infrastructures are also key issues.

3.3.2 Research environment and development

The dynamic real-time management of 'smart goods handling' by connected vehicles and equipment has been analysed in a set of research projects linked to the freight transport and logistics sub-theme. The project 'European inter-disciplinary research on intelligent cargo for efficient, safe and environment-friendly logistics' (EURIDICE) has defined initial concepts and developed technologies for an intelligent cargo system based on a combination of sensor networks, wireless communications, and ambient and artificial intelligence. However, 'Intelligent cargo in efficient and sustainable global logistics operations' (iCARGO) has validated such elements in an open freight-management ecosystem. The ongoing large-scale 'Cooperative logistics for sustainable mobility of goods' (CO-GISTICS) project is now developing and testing the market viability for cooperative logistics services with real-life logistical aspects in five domains that can be taken as references for the different key areas where C-ITS has impacts on freight transport and logistics, namely:

· intelligent truck parking and delivery areas management;

· cargo transport optimisation;

· carbon dioxide (CO_2) footprint monitoring and estimation;

· priority and speed advice;

· eco-drive support.

National projects are also progressing towards intelligent cargo handling, such as the Austrian 'Trimodal transhipment point inland port' (TRIUMPH II). This project is developing an intelligent communication hub connecting all actors in the transport chain to enable cross-modal process improvements (e.g. container handling at terminals) and event monitoring (e.g. estimated time of arrival).

The specific area where research advancements on C-ITS can be strictly linked to freight transport and logistics is the V2V communication between road freight vehicles to allow new operational schemes, and increased road safety and efficiency.

Truck platooning (the electronic coupling of two or more automated trucks driving in columns) is a clear example of how research has moved from advancements in V2V to V2I applications to put the platooning concept into practice in daily transport operations.

An entire set of projects including CHAUFFEUR, CHAUFFEUR II, 'Safe road trains for the environment' (SARTRE, 2009-2012) and, most recently, 'Cooperative dynamic formation of platoons for safe and energy-optimised goods transportation' (COMPANION, 2013-2016) demonstrated that significant fuel savings can be achieved because of the reduced aerodynamic drag of road trains, and there was increased comfort and safety for drivers.

These projects also indicated the need to develop real-time coordination systems to dynamically create, maintain and dissolve platoons taking into account information about the state of the infrastructure (traffic, weather, etc.)

During its Presidency of the Council of the European Union in 2016, the Netherlands launched the first European Truck Platooning Challenge[13]. This involved automated trucks from various manufacturers and transport operators platooning on public roads from several European cities to the Netherlands. The aim is to bring platooning one step closer to implementation.

Other projects such as 'Intelligent Route Guidance of Heavy Vehicles' (HEAVYROUTE), 'Urban Freight Energy Efficiency Pilot' (FREILOT) and 'Brabant In-Car II' (PARCKR) investigated the potential and commercial viability of some V2I implementations with sensing systems installed in highways, bridges, urban roads and parking areas.

HEAVYROUTE developed three main applications based on vehicle/infrastructure interaction models:

· a pre-trip route planning tool based on 'heavy goods vehicle (HGV) specific data' together with physical and legal restrictions on the infrastructure;

· a driving support application via real-time driver warning and recommended driving to avoid critical situations (e.g. roll-over);

· monitoring and management of HGVs at bridges with advice on speed, minimum vehicle spacing and/or lane change to keep appropriate loading of bridges.

The FREILOT project tested the effectiveness of giving priority to goods vehicles on certain roads and/or during certain times of the day in the city of Helmond in the Netherlands. Only goods vehicles equipped with acceleration/adaptive speed limiters and the eco-driving support function are eligible for this priority. The dynamic scheduling of delivery spaces is also offered as an additional service.

In addition, public-private initiatives such as PARCKR, part of the Dutch project Brabant In-Car II, worked well in deploying commercial solutions. PARCKR is the first mobile community for truck drivers to share information on truck parking areas. It is also the first smartphone app[14] to predict occupancy rates for truck parking areas, so reducing the number of drivers arriving at full truck parking areas and to allow them to properly plan their driving times.

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13 https://www.eutruckplatooning.com/default.aspx

14 http://www.parckr.com/en/

3.3.3 Research activities and outcomes

A total of 16 research projects were reviewed under the freight transport and logistics sub-theme.

Of these, 10 were financed by various European programmes, while six were funded by national programmes. Table 3-4 summarises the projects included in this analysis, their duration and source of funding.

3.3.3.1 Trends, knowledge gaps and policy requirements

In general, the achievements of the research from the technology point of view are already quite evident and in line with advancements on C-ITS architecture and protocol standards.

Table 3-4 Projects reviewed under the freight transport and logistics sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	Development of an Integrated Management System for Transport based on GSM	2005	National (Spain)
AMITRAN	Assessment Methodologies for ICT in Multimodal Transport from User Behaviour to CO_2 reduction	2011-2014	European (7th Research and Technological Development (RTD) Framework Programme)
CHAUFFEUR II	Promote Chauffeur II	2000-2003	European (5th RTD Framework Programme)
COGISTICS	COoperative loGISTICS for sustainable mobility of goods	2014-2016	European (Competitiveness and innovation framework programme (CIP)(2007-2013))
COMPANION	Cooperative dynamic formation of platoons for safe and energy-optimised goods transportation	2013-2016	European (7th RTD Framework Programme)
COMPASS4D	Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment	2013-2015	European (Competitiveness and innovation framework programme (CIP)(2007-2013))
EURIDICE	European Inter-Disciplinary Research on Intelligent Cargo for Efficient, Safe and Environment-friendly Logistics	2008-2012	European (7th RTD Framework Programme)
FREILOT	Urban Freight Energy Efficiency Pilot	2009-2012	European (Competitiveness and innovation framework programme (CIP)(2007-2013))
HEAVYROUTE	Intelligent Route Guidance of Heavy Vehicles	2006-2009	European (6th RTD Framework Programme)
iCARGO	Intelligent Cargo in Efficient and Sustainable Global Logistics Operations	2011-2015	European (7th RTD Framework Programme)
MSN	System for advanced monitoring of the means of transport and freight mobility in multimodal transport – Multimodal Network System	2002-2004	National (AMTRANS – Territory Arrangement and Transport Programme, Romania)
PARCKR	Brabant In-Car II: ParckR	2011-2012	National public-private (The Netherlands)
SARTRE	Safe road trains for the environment; Developing strategies and technologies to allow vehicle platoons to operate on normal public highways with significant environmental, safety and comfort benefits	2009-2012	European (7th RTD Framework Programme)
TEMR	Transportation Emissions Measurement and Reaction	2014-2015	National (Greece)
TRIUMPH II	Trimodal transhipment point inland port	2014-2016	National (Austria)
VMTL	Traffic Management in Transport and Logistics	2001-2005	National (Germany)

By making it possible to use the vehicles themselves as sensors, vast 'floating' (real-time) data becomes available to logistics operators. This leads to significant advantages in urban and interurban road environments and terminal activities. Enriched information services about the road environment are fundamental for drivers, but also for routing and pre-planning operations, and providing valuable support to driving decisions and supply chain management.

Specific technologies and sensors have been developed and introduced to fit with handling equipment and vehicles (i.e. HGVs, light duty vehicles (LDVs)).

In addition, the internet of things (IoT) will have an impact on logistics and supply chain management. The combined use of radio frequency identification (RFID) and ITS to automatically identify and track tags attached to freight vehicles has started to operate in yard management, shipping, and freight and distribution centres, but has evolved to become a pure networking technology by connecting single items and enabling the vision of creating smart objects.

While truck platooning has been shown to be feasible and to bring benefits in terms of fuel consumption and emissions (from the trucks), there remain some concerns on how the platoons may affect other users of the motorways, particularly at or near junctions. Research should be conducted into the safety implications of this and standards derived for determining where (and when) platooning may be safe.

3.3.3.2 Implications of the research results for future policy development

A stricter linkage with urban freight strategies is envisaged in the future. Numerous research activities and field tests on city logistics were carried out in several national and EU projects (e.g. the German 'Traffic Management in Transport and Logistics' (VMTL), the EU-funded projects 'Sustainable MARketdriven Terminal Solutions for Efficient freight Transport' (SMARTSET), 'Freight Electric Vehicles in Urban Europe' (FREVUE) and some 'City, Vitality, Sustainability' (CIVITAS) demonstrations). Positive results have also been achieved in terms of increased safety (e.g. the project 'Cooperative Systems for Road Safety' (SAFESPOT) demonstrated how the use of sensors can reduce collisions between road vehicles, including light and heavy duty ones). Despite these efforts, the functional linkage with C-ITS applications, as a core element of an integrated urban freight transport (UFT) scheme, has been quite weak up to now and should be reinforced with increased cooperation between UFT and C-ITS projects to build up new policy options.

Policy aspects for urban freight should also include cooperative technologies for increasing the level of safety on the road network, particularly for avoiding collisions between freight vehicles and vulnerable road users (e.g. blind-spot detection). The level of transferability of validated solutions from research projects into real-life use is also high in the V2V domain, favoured by the presence of numerous industry actors included in project partnerships.

Again the functional linkage between research results and policy development should be strengthened for those applications that have already been tested in more than one project (e.g. considering the truck platooning described above, there is a requirement for standards to determine where this solution can be used in a safe and useful manner).

3.4 Human-machine interaction

3.4.1 Preliminary recommendations

The aims of the research and development in the area of human-machine interaction (HMI) cover driver information and assistance systems. It seeks to improve the performance, reliability and comfort of C-ITS and to accelerate market uptake of C-ITS through enhanced user acceptance. This includes information provided to inform the driver about road conditions, hazards, etc. and information provided to other vehicles and the infrastructure to understand the driver's behaviour. The objective is to reduce the number of road traffic collisions and fatalities, so improving the safety of drivers and other vulnerable road users. Improvements in the design of the systems that provide the driver with information or feedback will contribute to reducing the multiple risks which compromise safety. It targets private transport and goods shipment.

3.4.2 Research environment and development

3.4.2.1 Overall direction of research

In general terms, the area of research on HMI has been focused around the interaction of vehicles with other systems. It seeks to transmit the vehicle's data to the driver to improve the information available to him/her and also from the driver to the vehicle and infrastructure. The interest in collecting and transmitting information is to make the infrastructure safer, more secure and more sustainable.

This topic constitutes a horizontal theme, which is picked up in several applications of C-ITS. The most prominent applications are safety systems, capacity management, route guidance, pre- and on-trip information (including support for travellers with special needs), and handling autonomous systems. Common fields of research on HMI systems include:

- appropriate filtering and highlighting of information;
- personalising information;
- selecting and combining several channels for information transmission;
- efficient interface systems;
- failure proofing;
- comfort and energy efficient interaction.

Figure 3-1 provides an overview of the most frequent expressions linked to the term 'Human-Machine Interaction' in the TRIP portal.

Figure 3-1 Word cloud on 'Human-Machine Interaction' extracted from TRIP

3.4.2.2 Fit with current policy and targets

In 1999, after initial assessments in 1997, the European Commission adopted a series of recommendations, the European Statement of Principles (ESoP), for designing HMI interfaces for in-vehicle information and communication systems. This was last updated in 2008 (EC, 2008). With new information to be provided in the cockpit (e.g. data on surrounding traffic), the ESoP on HMI might undergo another revision in the near future.

Of high importance for the design of HMI interfaces appears to be the European Commission's initiative on eSafety, the 'intelligent car initiative'. At a Member State level, the UK iMobility Forum and the German project cluster INVENT[15] produced a number of relevant studies and technology developments.

Ongoing and recently finalised research reported in TRIP on HMI cover the topics of electromobility, autonomous driving and multimodal urban transport systems:

- topics around electromobility are concerned with the interaction of drivers, vehicles and infrastructures for an optimal use of EVs' driving range through communication with other road users (e.g. FP7 projects 'Energy ManagEment and RechArging for efficient eLectric car Driving' (EMERALD) and 'ICT services for Electric Vehicle Enhancing the User experience' (ICT4EVEU));

- research in the field of cooperative road management systems as conducted by the FP7 projects PRESERVE, SAFETRIP and the German project 'Smart Adaptive Data Aggregation' (SADA, 2015-2018) address the topics of driver,

pedestrian and infrastructure interaction via user interfaces, and the security and privacy of information passed on via these interfaces;

- projects such as 'The Road User Information System of the Future' (SIMPLI-CITY, 2012-2015) (FP7) and 'Personalised Smart Travel Services on Urban Environments' (USMART, 2014-2015) (National funding, Greece) address multimodal travel information systems and the way personalised information should best be exchanged between users and service providers;

- to improve safety, security, awareness and decision-support methodologies, many standards have been developed (e.g. the UK project 'Development of Human-Machine Interaction (HMI) Standards' (1995 – 2006)).

Therefore, achieving a consensus through European standards for processing information is an important issue to be tackled in the coming years.

Potential gaps in research include the design of personalised HMI systems bundling different types of data sources in an intelligent and friendly manner, and including multichannel and multidirectional communication options and fail-safe technologies. With respect to the growing relevance of autonomous systems, interfaces allowing the driver to have ultimate control of the vehicle while not actually driving and keeping vulnerable road users in the loop creates a challenge for future ITS.

Greening and decarbonising transport, and making best use of prevailing infrastructure capacities requires a high level of connection, intelligence and automation in passenger and freight transport systems. Due to the rapid increase in use of smartphones, powerful mobile communication networks and innovative user interfaces through apps and websites, car, bike and ride-sharing systems have supported a shift of people's focus from owning a private car to using multimodal mobility services in western countries in the past decade. Powerful information, guidance and support systems, which find large-scale user acceptance via well-designed HMI interfaces, may help to reduce demand for individual car travel, supporting trips and shipments by more sustainable modes. As a result, they may play an important role in achieving the EU Transport White Paper (EC, 2011) targets on cutting greenhouse gas emissions, decarbonising urban travel and modal shift to rail and waterborne transport.

Moreover, there has been strong research in EVs with the aim of improving sustainability in road vehicles. The automobile market foresees that EVs will have an important share of the European Market in the future. Therefore, the efficient provision of information, driver-vehicle interfaces and architecture, and energy efficient interaction are among the topics that should be tackled in the following years.

Similarly, in-vehicle information provision through tangible, acoustic and visual channels have enabled the smooth

introduction of driver assistance systems. By disseminating these systems further, adding V2V and V2I communication, and by integrating several vehicle information systems (without overloading the driver with information) may help in approaching the zero fatality vision pursued by some Member States and by the European Commission's 2011 Transport White Paper (EC, 2011).

3.4.2.3 Overlaps and synergies within the European research community

HMI issues are common to most research activities on C-ITS. In addition to the optimisation of user interfaces for specific applications, such as safety systems and on-trip information, the interaction of such applications needs to be considered. Collaborative research and development efforts should, from time to time, examine the developments of HMI solutions across a range of applications and design situation-specific user interfaces, taking account of the users' capacity for attention and reaction. In this respect, noteworthy projects include:

- the FOT-Net (2008) project, which created a platform for knowledge exchange of FOTs;

- the 'European Large-Scale Field Operational Test on Active Safety Systems' project (euroFOT, 2011), which focused on driver assistance systems in Europe;

- the long-term, UK-funded project 'Development of Human-Machine Interaction (HMI) Standards' which has published different reports to homogenise information on this topic.

It is recommended that an open platform should be established for exchanging knowledge, data and concepts of HMI. This could run under the European Commission's C-ITS platform[16] (working group 9 on HMI issues), the European Commission's Initiative on Safety[17] and/or the Intelligent Car Initiative[18].

3.4.3 Research activities and outcomes

The projects reviewed under the HMI sub-theme are listed in Table 3-5.

Table 3-5 Projects included in the review of the HMI sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	Systems for Driver Assistance and for the Enhancement of Traffic Safety (VSS1999/307)	2003-2006	ARAMIS – ARAMIS information system
N/A	ITS towards 2020	2007-2010	Vegvesen/NPRA – Norwegian Public Roads Administration (various projects)
AIDE	Adaptive Integrated Driver-vehicle Interface	2004-2008	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
ARCOS	Research Action for Secure Driving	2002-2005	PREDIT 3: G.O.4 – Technologies for safety (Operational Group 4)
ATLANTIC	A Thematic Long-term Approach to Networking for the Telematics and ITS Community	2001-2002	FP5-IST – KA1 – Systems and services for the citizens
COMUNICAR	Communication Multimedia Unit Inside Car	2000-2003	FP5-IST – KA1 – Systems and services for the citizens
EFUTURE	Safe and Efficient Electrical Vehicle	2010-2013	FP7-ICT – Information and Communication Technologies
euroFOT	European Large-Scale Field Operational Test on Active Safety Systems	2008-2011	FP7-ICT – Information and Communication Technologies
FESTA	Field opErational teSts supporT Action	2007-2008	FP7-ICT – Information and Communication Technologies
FOT-Net	Networking for Field Operational Tests	2008-2010	FP7-ICT – Information and Communication Technologies
FVM	Driver Behaviour and Human-Machine Interaction	2001-2005	
HASTE	Human-Machine Interaction and the Safety of Traffic in Europe	2002-2005	European Commission, FP5
ID4EV	Intelligent Dynamics for fully electric vehicles	2010-2012	FP7-ICT – Information and Communication Technologies

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16 EC C-IST Platform: http://ec.europa.eu/transport/themes/its/news/c-its-deployment-platform_en.htm

17 EC Initiative on Safety: http://ec.europa.eu/transport/road_safety/specialist/knowledge/esave/ec_initiatives_on_esafety/index_en.htm

18 EC Digital Agenda: https://ec.europa.eu/digital-agenda/en/you-your-vehicle-and-technologies

Table 3-5 (Continued) Projects included in the review of the HMI sub-theme

Project acronym	Project name	Project duration	Source of funding
IMCAD	Improving the Cockpit Application Development Process	2002-2005	European (5th RTD Framework Programme)
INTERACTION	Differences and similarities in driver INTERACTION with in-vehicle technologies	2008-2012	FP7-SST – Sustainable Surface Transport
ISI-PADAS	Integrated Human Modelling and Simulation to Support Human Error Risk Analysis of Partially Autonomous Driver Assistance Systems	2008-2011	FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)
ITERATE	IT for Error Remediation and Trapping Emergencies	2009-2011	FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)
PISa	Powered Two-wheeler Integrated Safety	2006-2010	European (6th RTD Framework Programme)
PROTECTOR	Preventive Safety For Un-protected Road User	1999-2003	FP5-IST – KA1 – Systems and services for the citizens
RESPONSE 2	Advanced Driver Assistance Systems: From Introduction Scenarios towards a Code of Practice for Development and Testing	2002-2004	FP5-IST – KA1 – Systems and services for the citizens
SafeMAP	Socio-economic assessment of a dedicated digital map for road safety applications	2003-2008	DEUFRAKO – German-French co-operation for land transport research
SAFERIDER	Advanced telematics for enhancing the SAFEty and comfort of motorcycle RIDERs	2008-2010	EC, FP7
STARDUST	Towards Sustainable Town development: A Research on Deployment of Urban Sustainable Transport	2001-2004	FP5 EESD KA4 – City of Tomorrow and Cultural Heritage
VRUITS	Improving the Safety and Mobility of Vulnerable Road Users through ITS applications	2013-2016	FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)

3.4.3.1 Status of the technology

HMI interfaces constitute the linking elements between drivers and transport users on the one hand, and the technical systems on the other hand. The research content of most projects in the field deals with safety, with particular attention being paid to vulnerable road users; driver attention, distraction and work load; and the co-operation and handling of several assistance systems. To a lesser extent, research copes with HMI and traffic management or non-safety related traffic characteristics, such as congestion mitigation or fuel efficiency.

The technology for HMI systems advances as new sensor and vehicle concepts are developed, costs for technical components are reduced and user expectations change. Thus, the topic will remain under constant development, improvement and revision. With the help of public research and a better understanding of driver reactions and needs, powerful systems have been developed and are now becoming available on a wider range of vehicles than just the more expensive ones on which they were first introduced. While most public research concentrates on cars and trucks, other road vehicles, aviation and railways are covered by a few studies too.

3.4.3.2 In-vehicle information systems for cars and trucks

The exchange of information from internal and external sensors to car and truck drivers, and appropriate mechanisms for them to react, has been researched since the mid-1990s. Safety issues, caused by drivers being distracted through inappropriate or excessive messages, or due to incorrect information, constitute a core motivation for the majority of studies and demonstration projects. In 2003, the 'Communication Multimedia Unit Inside Car' (COMUNICAR, 2003) project applied a user-centred approach to define and test HMI concepts to protect drivers from information overload while driving. Sources handled by the information system included traditional vehicle status messages, several driver assistance systems and infotainment. Building on these results, the 'Human Machine Interaction and the Safety of Traffic in Europe' (HASTE, 2005) project specifically looked at critical traffic situations and the workload of drivers under such conditions. The study's conclusions defined the major constituents of a test regime for in-vehicle information systems (IVIS) under specific driving conditions.

Concerns about the different types of distraction and the ability of elderly drivers to handle the information flow of IVIS properly were raised by the study. As part of the INVENT project cluster funded by the German Government, the 'Driver Behaviour and Human-Machine Interaction' (FVM, 2005) study looked at learning behaviour of users with new driver assistance systems and the design of an inherently safe HMI. The results were implemented into a driving simulator for user experience and further system improvements.

On the development side, the integrated project 'Adaptive Integrated Driver-vehicle Interface' (AIDE, 2008) designed, developed and validated a generic interface to maximise the individual and combined efficiency of assistance systems for the enhanced safety awareness of drivers. The study developed a simulation model for enhanced human-machine interfaces, which allowed system settings to be tested under various traffic situations. As the technologies became mature, the attention of FP6 turned more towards testing sensors and driver assistance systems on the road and with real drivers. The euroFOT project tested 1 500 vehicles equipped with various types of sensor for two years on European roads. It was determined that 5.7% of accidents involving passenger cars and 0.6% involving trucks, together with some delays and 2% – 3% of fuel consumption, could be saved by a range of technologies including collision warning, ACC, blind spot warning and curve speed warning. It was also found that these technologies would have a high acceptance rate among drivers.

3.4.3.3 In-vehicle information systems for other applications

Even more so than conventionally powered road vehicles, electric vehicles require the driver's specific attention with regard to battery status, driving range and the presence of vulnerable road users. Besides the development of new vehicle hardware the 'Intelligent Dynamics for fully electric vehicles' (ID4EV, 2012) and, to some extent, the 'Safe and Efficient Electrical Vehicle' (EFUTURE, 2013) projects looked at the optimisation potential of a novel network system at a vehicle level and new HMI concepts for fully electric vehicles (FEVs).

Motorcyclists are vulnerable road users and should benefit from safety tools and HMI technologies dedicated to the specific situation of riding a two-wheeled vehicle. Based on numerous test rides, the 'Advanced telematics for enhancing the SAFEty and comfort of motorcycle RIDERs' (SAFERIDER (2008-2010)) and 'Powered Two-wheeler Integrated Safety' (PISa, 2006-2010) projects confirmed the applicability of rider assistance system technologies developed for passenger cars to powered two wheelers (PTWs). Prototypes have successfully been equipped with several safety features and appropriate human-machine interfaces were developed with noticeable safety improvements.

In civil aircraft, the flight deck and the underlying avionics are undergoing rapid development, including new human-machine interface technologies for improved safety. The project 'Improving the Cockpit Application Development Process' (IMCAD, 2005) addressed this development by setting new aeronautical standards for graphical cockpit display systems (CDS) and by providing prototyping tools for new CDS applications.

3.4.3.4 HMI in vehicle-to-infrastructure interaction

C-ITS imply the mutual interaction of vehicles and/or users. Accordingly, a part of research on how users interact directly with systems looks at the relationship between vehicles, infrastructures and third parties. In this context, the third parties are usually vulnerable road users (i.e. people who are less protected than car or truck drivers and passengers). The issue of vulnerable road users was discovered and researched in the late 1990s (e.g. by the project 'Preventive Safety For Un-protected Road User' (PROTECTOR, 2003) and the experimental study 'Research Action for Secure Driving' (ARCOS, 2005)). These projects identified a real potential for using radar, laser scanners, stereo video systems and other sensors to improve protection for vulnerable road users. However, they also identified a number of open issues, such as system tolerance for false alarms and ideal acoustical warning outputs. The objective of the 'Integrated Human Modelling and Simulation to Support Human Error Risk Analysis of Partially Autonomous Driver Assistance Systems' (ISI-PADAS, 2008-2011) project was to provide an innovative methodology to support risk-based design and approval of partially autonomous driver assistance systems (PADAS) focusing on elimination and mitigation of driver errors by an integrated driver-vehicle-environment modelling approach. The project developed the joint driver vehicle environment ('JDVE') simulation platform. The major advantage is a substantial increase in the speed of evaluation.

However, models simulating driver behaviour require the study of real humans steering vehicles. How technologies impact the long-term driving behaviours and skills of drivers across European countries was investigated by the 'Differences and similarities in driver INTERACTION with in-vehicle technologies' study (INTERACTION, 2012). Through road tests, focus groups and web interviews, it was found that some HMI technologies, such as speed warnings and telecommunication devices, are used very differently depending on ambient conditions.

The objective of the project 'IT for Error Remediation and Trapping Emergencies' (ITERATE, 2009-2011) was to develop and validate a unified model of driver behaviour and driver interactions with innovative technologies in emergency situations, which may be applicable and validated for all the surface transport modes. Drivers' age, gender, education and experience, and culture (whether regional or company/organisational) are factors that are considered with influences from the environment and the vehicle. The unified model has been developed and completed. The results obtained from the analyses show that, among other things, it is possible to unify the behavioural processes of surface vehicle drivers with a set of formulations that can be adapted to the specific mode of transport while maintaining the same modelling architecture.

More recent projects on C-ITS have moved on from the development stage and are testing fully equipped vehicles under real traffic conditions. For instance, the project 'Improving the Safety and Mobility of Vulnerable Road Users through ITS applications' (VRUITS, 2013-2016) seeks to improve the safety and mobility of vulnerable road users by means of cooperative traffic systems. Through trials in the Netherlands and Spain, the project intends to improve European policy by providing recommendations and action plans. Here, HMI not only means in-vehicle systems for car and truck drivers, but also communication and sensor devices carried by vulnerable road users. Tests at pedestrian crossings are intended to enhance the knowledge on usage rates and user preferences.

3.4.3.5 Embedding HMI in traffic and mobility management

The communication between users and technical systems continues to be a central task, even more so due to the steep rise of sharing systems, and multimodal mobility and logistics platforms. User applications that guide passengers and freight forwarders through complex sets of options may need to take account of a wide range of parameters. Anticipating critical conditions and emergency situations is also an important issue to reduce risks and, hence, improve safety in transport.

The objective of the ITERATE project (2011) was to develop and validate a unified model of driver behaviour and driver interactions with innovative technologies in emergency situations, which may be applicable to all surface transport modes. Drivers' age, gender, education and experience, and culture (whether regional or company/organisational) are factors that are considered with influences from the environment and the vehicle. The model has been developed and completed. The results obtained from the analyses show, among other things, that it is possible to unify the behavioural processes of surface vehicle drivers with a set of formulations that may be adapted to the specific mode of transport and maintain the same modelling architecture.

In the face of a high number of collisions occurring because road users were not aware of prevailing road conditions, the 'Socio-economic assessment of a dedicated digital map for road safety applications' (SafeMAP, 2008) project developed a navigation map based on a 'geo-localised database' concept including road-safety-related data. The project evaluated the navigation map's socio-economic impact and its suitability for use by drivers. Based on this map, an on-board anticipation aid application was developed and evaluated with respect to its suitability for the driver and potential business cases.

The aim of the 'Towards Sustainable Town development: A Research on Deployment of Urban Sustainable Transport' (STARDUST, 2004) project was to assess the extent to which ADAS and automated vehicle guidance (AVG) systems can contribute to a sustainable urban development, not only in terms of direct impacts on traffic conditions and the environment, but also in terms of impacts on social life, economic viability, safety, etc.

3.4.3.6 Implications of the research results for future policy development

Tasks for future research include:

- establish an open platform for exchanging knowledge, data and concepts of HMI (for example, a C-ITS Platform initiative on safety or intelligent car initiative);

- integrate vehicle and HMI concepts for all types of users, including the elderly and disabled;

- better integration of security in HMI topics;

- the security of data and private information held by HMI interfaces needs special attention in preparation for fully automated vehicles in the future.

3.5 Information systems/platforms

3.5.1 Preliminary recommendations

The availability of information systems and platforms in the transport domain is the precondition for every C-ITS application. Indeed, cooperative mobility – intended as the interconnection of users, vehicles and infrastructure – could not occur in the absence of system architectures and platforms that enable the collection, processing, creation and sharing of information. Thus, the review on this sub-theme could, potentially, have encompassed all ITS-related projects that have been carried out. However, to ensure the relevance of the analysis, the review concentrated on research projects funded by the EU and national governments in the last decade.

EU-funded projects are polarised around a certain number of specific topics called in the EU research work programmes (e.g. cooperative mobility, electromobility, clean and efficient multimodality), while the national research is more focused on the design and development of local (i.e. mainly at urban or regional level but, in some cases, also on national architectures) information systems and platforms. Moreover, in some countries, the national research also covered technological advancements in the field of V2V and V2I communication.

3.5.2 Research environment and development

3.5.2.1 Overall direction of European-funded research

Over the last decade, EU-funded research on information systems and platforms has seen very substantial development efforts aimed at creating and deploying a new generation of transportation systems that are able to satisfy a variety of objectives. This review has allowed the following main research directions to be identified:

1. The development of advanced ICT system architecture and on-board applications to support FEV deployment by improving their energy efficiency, optimising recharging interfaces and methods, extending their driving range (i.e. eliminating the 'range anxiety' phenomenon)' and achieving better integration of the FEV in the smart grids and cooperative infrastructure.

Projects addressing this topic contributed also to the European Green Cars Initiative (EGCI), a public-private partnership launched in 2008 to respond to the global economic crisis as part of the European Economic Recovery Plan. Several projects focused on electromobility advancements, including:

• 'Efficient Cooperative infrastructure for Fully Electric Vehicles' (eCo-FEV, 2012-2015) that developed an open architecture for integrating FEVs into cooperative infrastructure systems by mutualising and exploiting real-time information from EVs and independent EV-related infrastructures. The back-end data system collects and enables the information exchange of real-time data from different independent infrastructure systems and FEVs, so allowing precise EV telematics services and charging management based on real-time information.

• 'Co-operative ITS Systems for Enhanced Electric Vehicle Mobility' (MOBILITY2.0, 2012-2015) that developed an in-vehicle commuting assistant app to support EV drivers with the process of optimised journey planning, reserving charging points and multimodal navigation, so ensuring that drivers of EVs with low battery charge can find and reserve charging points. The app also provides information on the cost of electricity at charging points, thus supporting dynamic electricity pricing for charging EVs, where lower electricity pricing incentivises the use of less frequently used charging points.

• 'ELectric Vehicle communication to Infrastructure, Road services and Electricity supply' (ELVIRE, 2010-2013) that focused on the development of an on-board communication and service platform that provides the driver with estimates of the expected energy consumption for a given route taking into account topography, driving behaviour and vehicle status information. The platform was developed using realistic use-cases for EVs. The project also explored viable business models on how to realise a full coverage charge infrastructure, when selling energy to EV users may not a major revenue opportunity.

2. The development of the European Wide Service Platform (EWSP) for cooperative system enabled services, aiming at providing components and tools for fostering interactions between users and suppliers of mobility services. In this field:

• SIMPLI-CITY provided results in three distinct fields:
  - data as a service;
  - the mobility services framework;
  - the personal mobility assistant.

Regarding data as a service, SIMPLI-CITY delivered methodologies and software solutions allowing the integration of mobility-related data from various, technologically heterogeneous, data sources. Thus, developers do not have to deal with different data formats and protocols anymore. Instead, they are able to integrate data based on a unified data model and automated data transformations. The SIMPLI-CITY mobility services framework includes a complete service runtime environment, which lets software developers run their own services in a cloud-based environment, and a service marketplace aimed at software developers who want to monetise their products. Finally, the personal mobility assistant can be installed on the user's smartphone and provides a voice-based, multimodal user interface. Thus, road users – and especially drivers – are able to interact safely with apps in an intuitive way.

• Similarly, the ongoing project 'Europe-Wide Platform for Connected Mobility Services' (MOBiNET, 2012-2016) is exploring three key areas of innovation:
  - a global multi-vendor business-to-business e-market-place and service directory where service providers can publish and exchange their products and services, thereby enhancing their offering and the customer base;
  - a 'MOBiAGENT' that is accessible on user devices linked to the service directory where service providers can advertise their offerings to a much wider customer base;
  - a service directory including a set of reference transport and mobility services, and a toolkit that can be used by developers for new or enhanced service offerings.

- The MyWay project (2013-2016) has developed and validated an integrated platform, the European Smart Mobility Resource Manager, which includes cloud-based services and facilities for collecting and processing community-supplied information. The purpose is to address the efficient and seamless integration and use of complementary mobility services including all transport modes and mobility sharing schemes.

- The goal of the 'Open Vehicular Secure Platform' (OVERSEE, 2010-2012) was to provide a standardised, generic communication and application platform for vehicles, that ensured security, reliability and trust of external communication and simultaneous running applications.

Earlier steps taken towards the development of a Europe-wide service platform can be found in previous projects. An example is:

- 'Global System for Telematics' (GST, 2004-2007) which aimed to create an open and standardised end-to-end architecture for automotive telematics services. It developed an environment in which innovative telematics services could be developed and delivered cost-effectively, so increasing the range of economic telematics services available to manufacturers and consumers. With GST, drivers and occupants can access a dynamic range of online safety, efficiency- and comfort-enhancing services wherever they drive in Europe. They can also access their portfolio of services throughout Europe using the same vehicle terminal.

3. The development of ICT supporting clean and efficient multimodal mobility for improving energy efficiency and reducing CO_2 emissions. Here, the focus is on the integration of all transport modes, following Europe's transport policy principle of co-modality but, in particular, between road transport and other modes. Projects in this field encompass the development of advanced multimodal travel and information systems for individual and collective transport; and new tools, systems and services supporting environmentally aware driver behaviour adaptation and route and access planning for eco-routing. These include:

- Persuasive Advisor for CO_2-reducing cross-modal Trip Planning' (PEACOX, 2012-2015) that developed a system to increase the environmental awareness of travellers by automatically detecting users' trip purpose through the analysis of behavioural patterns, allowing the tailoring of trip suggestions to these purposes. Advanced door-to-door CO_2 emission models were also developed to provide accurate feedback on the ecological carbon footprint and exposure levels in trip planning, and during travelling and car driving. Furthermore, PEACOX utilised and extended persuasive interface strategies to give feedback about the ecological impact of individual behaviour and to make the ecologically friendliest behavioural pattern visible and attractive.

- 'Personal Transport Advisor: an integrated platform of mobility patterns for Smart Cities to enable demand-adaptive transportation systems' (PETRA, 2014-2017) aims to develop

a service platform connecting the providers and controllers of transport in cities with travellers in a way that information flows are optimised while respecting and supporting the individual freedom safety and security of the traveller. Cities will get an integrated platform to enable the provision of citizen-centric, demand-adaptive, city-wide transportation services. Travellers will get mobile applications that assist them in making travel priorities and choices for route and modality. The work will result in a city-wide transportation system comprising several sub-systems that involve transportation services and policies to adapt to the travel demands of the citizens. To achieve this, the platform will fuse different data from various city sources, travel operators and citizens; perform a broad class of predictive analytics; and detect the real-time events based on the analytical information and real-time data. It will further provide information services to the transportation service providers and city stakeholders to optimise the transportation offerings according to the citizens' interests.

- 'Service Platform for the Connected Traveller' (ITRAVEL (2008-2009)) developed a virtual, proactive and context-aware travel assistant that uses real-time information and continuously monitors the trip progress, so guiding travellers along their itinerary, alerting them whenever there is a problem or an interesting travel alternative. If a chosen trip chain cannot continue the way it was planned, it (proactively) immediately offers travel alternatives and makes all the necessary arrangements, such as purchasing e-tickets and changing hotel bookings.
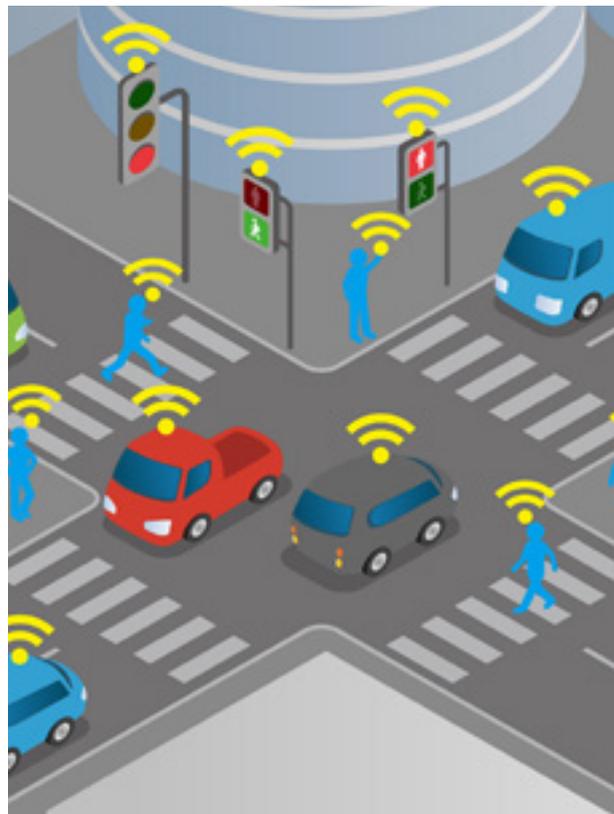
4. FOTs are an important push in ICT research in Europe through the validation of the effectiveness of ICT-based systems and functions for safer, cleaner and more efficient transport in a real environment. Therefore, FOTs help to fill the gap between R&D and market deployment phases, by assessing the impact of mature systems and functions using real data, analysing driver behaviour and acceptance and improving awareness about the potential of ITS By doing so, they create a socio-economic acceptance of new ICT solutions and enhance their take-up in real applications.

In this context, FOT-Net (2008-2010), FOT-Net 2 (2011-2013) and FOT-Net Data (2014-2016) are all EU-funded support actions operating an international networking platform with the aim of promoting the efficient sharing and re-use of available FOT datasets and building a detailed catalogue of available data and tools.

To improve the significance, visibility, comparability and transferability of FOT results at national and European level, a common European FOT methodology has been developed by the 'Field opErational teSts supporT Action' project (FESTA, 2007-2008). This project developed a handbook on FOT methodology, which is now owned by the FOT community and is promoted and updated by FOT-Net.

3.5.2.2 Overall direction of national funded projects

Interesting developments on information systems and platforms also appear on the national research panorama.

With the goal of improving traffic safety and traffic flow in the future, the German project 'Adaptive and Cooperative Technologies for the Intelligent Vehicle' (Aktiv, 2006–2010) brought together automobile manufacturers; electronic, telecommunication and software companies; and research institutions. The project's goal was to design, develop and evaluate novel driver assistance systems, knowledge and information technologies, solutions for efficient traffic management and V2V and V2I communication for future cooperative vehicle applications.

'Dynamic Information and Applications for assured Mobility with Adaptive Networks and Telematics infrastructure' (DIAMANT, 2008-2013) was a German project that focused on the development of V2V and V2I with the objective of increasing the efficiency and safety of road traffic and implementing the following applications:

- information for drivers;
- warnings for drivers;
- virtual influence on road traffic.

'Smart Parking Solutions' (CITY2.E 2.0, 2014-2015) was a German project that focused on a practical demonstration of an intelligent parking space monitoring and control system – including EV charging facilities. The main parts of the project included developing a prototype holistic parking detection, a practical real-world test, and a system architecture for monitoring and control of parking spaces. The solution that has been developed is to be integrated into the Berlin traffic information system. The aim is to develop an adaptive prediction solution using machine learning methods to give estimations of future parking area occupation in a 'virtual garage'. In this way, users can select the exact destination of their trip by the local parking space situation predicted for the time of their arrival. Consequently, it is possible to make a decision about the ideal mode of transport (e.g. taking an EV, public transport or a combustion-engine vehicle).

To take further steps to combat congestion, it is essential to 'connect' to the roadside infrastructure, and use additional information and tools that are external to the vehicle. 'Connected Cruise Control' (CCC, 2010-2013) is a Dutch project that developed a connected cruise control system providing tactical driving advice on speed and lane choice based on downstream traffic-flow conditions. The core of the overall system is an in-vehicle telematics platform with General Packet Radio Service (GPRS) communication with a central system collecting and processing traffic data. The traffic-flow prediction and driver-advice modules as well the HMI interface in the vehicle, were developed and tested successfully. Traffic-flow simulations showed potential delay reductions of up to 30%.

'Strategic Platform for Intelligent Traffic Systems' (SPITS, 2009-2011) was a Dutch project, tasked with creating ITS concepts that can improve mobility and safety. The SPITS project focused on three main areas:

- traffic management systems;
- in-vehicle solutions ensuring a connected link between the vehicle and the outside world;
- a service download and management solution.

Another Dutch project BETTER INFORMED ON THE ROAD: ROADMAP 2013–2023 (2013-2023) aims to realise a smart and consistent mix of information using smartphones, navigation systems and collective information channels on, above and alongside the road. This will contribute, in a positive way, to accessibility, safety and the quality of life in and around the infrastructure in the Netherlands and increase the (international) competitiveness of the Dutch business sector.

'Intelligent System for Traffic and Road-infrastructure Related Data' (iSTRADA, 2015-2016) is an Austrian project that aims to design a data-based system and technology framework to support the safe and efficient operation of a transport infrastructure through the exploitation of big data. Available information (such as infrastructure, vehicle fleets, environmental and collision data), and existing technologies and methods are studied to develop specific research and implementation concepts in the areas of maintenance, environmental impact, risk minimisation and increased efficiency. The outputs will assist the supporting infrastructure managers in their decision-making, evaluations of the feasibility and potential for further developments.

'ITS Austria West' (ITSAW, 2011-2014) was an Austrian project that aimed to develop and implement a traffic simulation system for an integrated platform of traffic information for the federal provinces of Upper Austria and Salzburg. A further requirement for the new ITS was to ensure compatibility with other systems in the neighbouring regions and to deliver the traffic information to the centralised Austrian Traffic Data Platform.

'Mobility and Tourism in Urban Scenarios' (MOTUS, 2015) was an Italian project that focused on developing a set of services able to gather, aggregate and interpret (in real time) urban mobility data from different infrastructures scattered across urban areas and in historic cities. By providing information on urban mobility, citizens are able to plan their journey in real time. Tourists are also engaged in the process by providing information, and using the content and value added data. By transmitting information via smartphones, tablets and desktops, MOTUS becomes a virtuous circle that actively engages the various actors involved in a system of mutual cooperation.

Similarly, USMART was a Greek project that focused on developing a suite of novel, smart mobility services (iServices) that were based on mobile technology and supported city residents and visitors/tourists in reaching their final destination in the most efficient and suitable way using public and/or private transport. All iServices were developed and demonstrated for major sporting and cultural events. In addition, a smartphone application for innovative data collection was developed, serving as a personal life logger and collecting real-time information through sensors (such as wireless fidelity (Wi-Fi), Global System for Mobile Communication (GSM™) and GPS).

'Urban Platform for Advanced and Sustainable Mobility' (PUMAS, 2009-2012) was a French project aimed at developing a software platform for collecting and analysing road-traffic information in real time. The software platform was aimed at local public authorities (towns, cities, regions) and, through the use of accurate and real-time vehicle speed and journey times, intended to provide them with:

- knowledge of real-time traffic conditions along urban and peripheral networks;

- a precise tool for urban mobility decision-making;

- an estimate of greenhouse gas and other pollutant emissions, in real time and throughout the area.

'Socio-economic assessment of a dedicated digital map for road safety applications' (SafeMAP, 2003-2008) was a joint German and French project. It aimed to develop a new navigation map using a geolocalised database concept including road-safety-related data; evaluate its socio-economic impact and suitability for drivers and, subsequently, propose examples of an on-board application to aid 'anticipation'. Informing drivers sufficiently early of any facts relating to the so-called 'risk' issues ahead and alerting them whenever their driving (speed, course, etc.) is inappropriate for the road section about to be entered enables them to increase their level of anticipation and adapt their driving according to the situation ahead. In this context, relevant technical specifications were also developed and organisational and juridical requirements for creating and maintaining this database examined.

3.5.3 Research activities and outcomes

The projects reviewed under the information systems/platforms sub-theme are listed in Table 3-6.

Table 3-6 Projects reviewed under the information systems/platforms sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	Better informed on the road: roadmap 2013 – 2023	2013-2023	Netherlands
Aktiv	Adaptive and Cooperative Technologies for the Intelligent Traffic	2006-2010	Germany
CCC	Connected Cruise Control	2010-2013	Netherlands
CITY2.E 2.0	Smart Parking Solutions	2014-2015	Germany
DIAMANT	Dynamic Information and Applications for assured Mobility with Adaptive Networks and Telematics infrastructure	2008-2013	Germany
eCo-FEV	Efficient Cooperative infrastructure for Fully Electric Vehicles	2012-2015	European
ELVIRE	ELectric Vehicle communication to Infrastructure, Road services and Electricity supply	2010-2013	European Union
FESTA	Field opErational teSts supporT Action	2007-2008	European Union

Table 3-6 (Continued) Projects reviewed under the information systems/platforms sub-theme

Project acronym	Project name	Project duration	Source of funding
FOT-Net	Field Operational Tests Networking and Methodology Promotion	2008-2010	European Union
FOT-Net 2	Field Operational Tests Networking and Methodology Promotion	2011-2013	European Union
FOT-Net Data	Field Operational Tests Networking and Methodology Promotion	2014-2016	European Union
GST	Global System for Telematics	2004-2007	European Union
iSTRADA	iSTRADA Intelligent System for Traffic and Road-infrastructure Related Data	2015-2016	Austria
ITRAVEL	i-Travel – Service Platform for the Connected Traveller	2008-2009	European Union
ITSAW	ITS Austria West	2011-2014	Austria
MOBILITY2.0	Co-operative ITS Systems for Enhanced Electric Vehicle Mobility	2012-2015	European
MOBiNET	Europe-Wide Platform for Connected Mobility Services	2012-2016	European Union
MOTUS	Mobility and Tourism in Urban Scenarios	2015-	Italian
MyWay	European Smart Mobility Resource Manager	2013-2016	European Union
OVERSEE	Open Vehicular Secure Platform	2010-2012	European Union
PEACOX	Persuasive Advisor for CO_2-reducing cross-modal Trip Planning	2012-2015	European Union
PETRA	Personal Transport Advisor: an integrated platform of mobility patterns for Smart Cities to enable demand-adaptive transportation systems	2014-2017	European Union
PUMAS	Urban Platform for Advanced and Sustainable Mobility	2009-2012	France
SafeMAP	Socio-economic assessment of a dedicated digital map for road safety applications	2003-2008	Germany; France
SIMPLI-CITY	SIMPLI-CITY The Road User Information System of the Future	2012-2015	European Union
SPITS	Strategic Platform for Intelligent Traffic Systems	2009-2011	Netherlands
USMART	Personalised Smart Travel Services on Urban Environments	2014-2015	Greece

3.5.3.1 Status of the technology

Over the past years, the development of information system and platforms to enhance travel information and traffic management has been key in European and national research. This trend is continuing and shows that greater synergy between initiatives and investments made by private and public parties is sought.

The dividing line between traffic management and mobility demand management is becoming blurred by technological developments and the emergence of information services targeted at individuals. Further cooperative services with requirements for open European standards are continuing to emerge.

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R e s e a r c h   T h e m e   A n a l y s i s   R e p o r t
C o o p e r a t i v e   I n t e l l i g e n t   T r a n s p o r t   S y s t e m s

3.5.3.2 Implications of the research results for future policy development

It can be expected that future research will focus on providing information services that are increasingly targeted to the needs and wishes of individuals to enable them to make the best possible choices when travelling before and during their trips. Due to these services, users will be able to travel from door to door quickly, safely, comfortably, in an environmentally friendly way and for an acceptable price.

More than ever, providing travellers with accurate and up-to-date travel information will become a joint public-private effort, and this information will have a more multimodal character and require cooperation between all transport modes and sectors. Ultimately, the reliability experienced by travellers will depend on the consistency between the information they receive and the actual situations they encounter during their trip. A greater role will be played by systems capable of gathering, processing and enriching big data in real time. Communication with travellers will largely take place by a mix of different information channels such as navigation systems, smartphones, infrastructure and in-vehicle devices.

To progress towards the large-scale implementation of successful mobility solutions, it is crucial that tests and trials are performed for those solutions. International coordination in such trials and experiments is seen as key to increase the efficiency and learning capacity of researchers and market parties, reduce the knowledge divide among European regions and increase the competitiveness of the European transport sector as a whole.

Another key aspect to be considered when moving from research to large-scale deployment is the 'chicken and egg' problem – how to stimulate investment and on which kind of business model could be viable in the sector. In this respect, in November 2014, the European Commission's Directorate-General for Mobility and Transport (DG-MOVE) created the 'Platform for the Deployment of Cooperative Intelligent Transport Systems in the European Union' (C-ITS Platform, 2014) with the clear intention of tackling the chicken and egg problem, and of developing policy recommendations and proposals for action for the Commission and the relevant actors of the C-ITS value chain. The C-ITS Platform delivered its final report in January 2016, in which it addressed key issues for the deployment of C-ITS:

- the common technical framework necessary for the deployment of C-ITS;

- the legal questions related to C-ITS;

- the "legitimacy" of the deployment of C-ITS, i.e. the fact that the deployment of C-ITS can be justified and fostered at all levels;

- international cooperation.

3.6 Motorway applications

3.6.1 Preliminary recommendations

The motorway applications sub-theme has attracted increased attention in recent years due to the progress of several high-profile FOTs and pilot projects. A selection of basic C-ITS services suitable for advanced testing and deployment in vehicles has been developed for motorway applications; these services are nearing a technology readiness level (TRL) appropriate for commercial launch. This viewpoint is supported by the CAR 2 CAR Communication Consortium (C2C-CC), a non-profit organisation initiated by European vehicle manufacturers and equipment suppliers, which believes that commercial deployment can be expected in European vehicles in 2019 (C2C-CC, 2015).

Although fewer projects were identified under the motorway applications sub-theme compared with some other sub-themes, the projects are generally large-scale, multi-million euro projects that receive funding from a variety of sources – including European-level funding, national research programmes and public-private partnerships. Research in this area shows a very good fit with European policy objectives in the areas of safety, the environment and connecting the European transport network. In addition to these goals, many of the priority areas included in the ITS Directive have been demonstrated by research within this sub-theme.

Analyses of research projects under motorway applications indicated that safety applications are well researched, but other applications have been trialled less frequently. In addition, commercial deployment will require other aspects of motorway applications to be addressed in more depth to ensure that robust business models can be generated. These research gaps include:

- **Application of C-ITS motorway services to other vehicle types, such as freight** – testing C-ITS services in freight vehicles is evident in the urban applications sub-theme, but has not received much attention under motorway applications, particularly in large European deployment projects. This could be explained by the safety focus of many projects; greater attention to areas such as efficiency may attract the participation of researchers in the field of logistics. Further research in this area would support priority area II ('Continuity of traffic and freight management ITS services') of the ITS Directive. It would also link well with the wider European transport strategy and the cross-border connection of transport networks.

- **Quantifying the wider costs and benefits of C-ITS motorway applications under development** – demonstrating that C-ITS motorway applications are cost-effective and can deliver benefits in a variety of areas is paramount to ensuring the success of this technology. The impacts on areas such as fuel consumption, emissions, congestion and driver comfort are less well understood than safety. Also, the application must bring economic benefits to road operators if investment for infrastructure is to be secured. Although research is ongoing in this area, a greater emphasis on data collection

and analysis would help to understand the advantages of C-ITS. This would contribute to priority area I ('Optimal use of road, traffic and travel data') of the ITS Directive.

- **Sharing results and communicating key achievements** – project objectives are often very detailed, well documented and show a good fit with policy requirements. However, communications of the main research outputs are often difficult to find online. Publication of concise summaries of the main research outputs may help generate greater interest in this area and attract funding from a variety of stakeholders in the future. Improved knowledge sharing also has the potential to accelerate research and may help to engage the public with exciting innovations in this sub-theme.

- **User acceptance testing** – as with the above point, obtaining user buy-in for novel technologies is a vital part of the development process. Research in this area is also relevant to priority area Ill of the ITS Directive (ITS road safety and security applications).

The areas listed above could be addressed through further investment into well-designed deployment projects to generate data and identify the most important aspects of motorway applications for further research. Based on the outcomes, further technological developments to improve systems could then be encouraged. It is also equally important to support the less mature technologies in this area to ensure continued progress in the future.

3.6.2 Research environment and development

3.6.2.1 Overall direction of research

The assessment of research projects in the motorway applications sub-theme revealed that a large number of research projects focused on the deployment and evaluation of trial systems, which suggests that research in this area is relatively well advanced. Rather than focusing on specific research areas, these projects tend to have very broad objectives and aim to demonstrate that C-ITS has the potential to contribute to a number of transport priorities in Europe, including road safety, traffic efficiency, the environment and driver comfort.

Deployment projects are the final stage of the research journey prior to commercial deployment and have been carried out in a number of Member States (see Table 3-7). These deployment, or FOT, projects intend to:

- showcase research developments and evaluate the benefits of C-ITS in real-world driving situations;

- demonstrate the applicability of different C-ITS services and technologies;

- connect European countries via Trans-European Transport Network (TEN-T) corridors;

- share and transfer learning between different European projects, thus ensuring interoperability.

Larger scale deployment projects are often co-financed by public-private partnerships and European-level funding. This has the potential to be hugely beneficial for the acceleration of technology development in Europe as it promotes communication between key stakeholders who will be involved in the commercial deployment of C-ITS. To help secure future investment, motorway applications need to be relevant and deliver benefits to a wide range of stakeholders, especially road operators, who may value certain services and, in some cases, be responsible for managing these services.

Table 3-7 List of deployment projects

Project	Locations	Objectives and applications
BaSIC	Czech Republic	Demonstration project for C-ITS focused on V2I and V2V technologies. Safety and information services such as roadworks warning, emergency vehicle approaching warning and speed-limit information were trialled.
Brabant In-Car II: ParckR	Netherlands	Logistics sub-project for truck drivers within Platform Beter Benutten (see below). Trial of an intelligent truck parking app for motorway parking facilities, intended to increase driver comfort and safety by helping drivers to comply with driving-time regulations.
Cooperative ITS Corridor	Netherlands Germany Austria	Aims to deploy C-ITS services to improve safety and reduce congestion. Initially, two services (road works warning and vehicle data for improved traffic management) will be deployed.
COOPERS	Netherlands Germany Austria Italy France Belgium	Developing and testing new safety-related services, equipment and applications using two-way communications between road infrastructure and vehicles from a traffic management perspective.
NordicWay	Sweden Finland Denmark Norway	Aims to evaluate the technical performance, impacts, costs and acceptance of cellular-network-based C-ITS services. Key objectives include improving road transport safety, efficiency and comfort of mobility.
Platform Beter Benutten	Netherlands	C-ITS is one aspect of Platform Beter Benutten, a Dutch programme to improve accessibility and reduce congestion. The platform is working on a number of projects and services to deliver real-time traffic information and navigation advice, open-parking data and services to limit the effect of shockwave traffic jams on motorways.
SCOOP@F	France	The primary objective of the SCOOP@F project is to deploy C-ITS services and improve the safety of road transport. Additional services in the area of traffic information are expected at a later date.
SCORE@F	France	Collaborative C-ITS research project, which aimed to evaluate services prior to a larger scale deployment project (SCOOP@F). C-ITS services were in the areas of safety and traffic management.
SISCOGA	Spain	Intelligent corridor project which aimed to evaluate C-ITS and assess interoperability between different technology providers and vehicles. Safety, traffic management and driver information services such as probe vehicle data, speed limit signs and merge assistant were trialled.
Testfield Telematik	Austria	Aimed to contribute towards making transport safer, more efficient and more environmentally friendly. The project involved the development, operation and demonstration of cooperative mobility services in the Vienna region.

3.6.2.2 Trends, knowledge gaps and policy requirements

A key trend in C-ITS research is safety, which aligns well with the EU transport strategy. This trend is also evident in the motorway applications sub-theme and has been continuously present over time, perhaps because safety has, historically, been a key driver for C-ITS research.

Many of the projects analysed addressed safety issues, including 'Active Barrier – Ideation and Development of a New Innovative Barrier based on an Innovative Concept of Safety combined with structural function (passive function) and active function' (Active Barrier, 2011-2014), 'Co-operative Networks for Intelligent Road Safety' (COOPERS, 2006-2010), 'Fully Automatic Integrated Road Control' (FAIR, 2005) and SARTRE. For example, in the COOPERS project, an intelligent road safety system was developed using V2Iommunication. This was facilitated by the continuous exchange of data via wireless networks. The COOPERS C-ITS package consisted of 12 services with a range of safety and traffic information functionalities, such as wrong-way driver warning, roadwork information and estimated journey time. This system was tested under real conditions on heavily used sections of European motorways on four different test sites, which ran through six European countries. The results of this project successfully demonstrated the feasibility of C-ITS and proved to be a useful foundation for later European C-ITS projects such as 'DRIVing implementation and Evaluation of C2X communication technology in Europe' (DRIVE C2X, 2011).

Other applications for C-ITS, such as reducing congestion and the environmental impacts of transport, are less thoroughly researched than safety in motorway applications. Future research projects in this area could seek to establish whether there is potential for benefits to be delivered in these areas, which would then help to direct further research.

3.6.2.3 Fit with current policy and targets

Projects reviewed in this sub-theme fit extremely well with current EU policies and targets. Many of the projects are safety focused and put the EU's 2050 road-safety goal at the forefront of their objectives. Another prominent goal in the motorway applications sub-theme is the desire to improve the provision of traffic information through the use of V2V and V2I communication.

Overall, motorway applications research shows relevance to all four priority areas in the field of ITS that are listed in the ITS Directive. In particular, priority areas I (Optimal use of road, traffic and travel data), III (ITS road safety and security applications) and IV (Linking the vehicle with the transport infrastructure) are being investigated in the most depth.

SARTRE is an excellent example of a research project that addresses a variety of target areas. The project aimed to develop a prototype system to promote the safe adoption of vehicle platoons (road trains) that could operate on public highways. SARTRE aimed to address environmental, safety and congestion issues, while encouraging user acceptance through increased driver comfort. Results from the project also showed that fuel savings and environmental benefits could be achieved, which are important factors for commercial viability.

However, the 'Analysis of MassIve Data Streams' (AMIDST, 2014-2016) project primarily targeted priority area I of the ITS Directive. It explored the optimal use of automotive data (e.g. vehicle speed, position, acceleration, orientation within lane, trajectory and free space for a manoeuvre) for manoeuvre recognition in motorway traffic. It focused on optimising the efficiency of existing techniques to enable automated monitoring and analysis of streaming data. The identification and interpretation of driver manoeuvres is anticipated to have a role in road safety and could form part of ADAS in the future.

3.6.2.4 Overlaps and synergies within the European research community

There are many overlaps and synergies between projects in this sub-theme, which results in a reasonable degree of cooperation within the European research community. Numerous projects have built on each other's successes. Initial projects demonstrated the feasibility of C-ITS on motorways and follow-up projects scaled up the technology in terms of the number of services/applications trialled and the number of vehicles and roads covered.

For example, in 'Système Coopératif Routier Expérimental @ France' (SCORE@F, 2010-2013) a nationally-funded French C-ITS research project, FOTs were carried out in collaboration with the 'Co-Pilot for an intelligent road and vehicular communication system' (CO-DRIVE, 2014) and DRIVE C2X projects. The SCOOP@F project is now following on from SCORE@F by testing C-ITS on a much larger scale in France. Another good example of overlaps between projects is the Austrian section of the Cooperative ITS Corridor (commonly referred to as the 'European Corridor – Austrian Testbed for Cooperative Systems' (ECo-AT, 2013)). Prior to this, the project Testfield Telematik (2011-2013) developed applications within Austria.

A good level of interaction between deployment projects is important because of:

- the costs associated with testing new technologies in vehicles;
- the variety of different technologies and services being trialled;
- interoperability issues;
- transfer of learning throughout Europe.

In particular, cross-border projects are helping to provide solutions for interoperability, ensuring that cooperative systems work across Europe and with a variety of technology providers.

3.6.3 Research activities and outcomes

A total of 23 research projects were reviewed under the motorway applications sub-theme (including six classified as having 'Short Profiles' in TRIP).

The projects were analysed to understand the research direction, technology status and results obtained in the area of motorway applications.

Of the 23 research projects reviewed under motorway applications, five were financed by various European programmes, while 18 were funded by national programmes. Table 3-8 summarises the projects included in this analysis (excluding the 'Short Profile' projects), their duration and source of funding.

Table 3-8 Projects included in the motorway applications sub-theme assessment

Project acronym	Project name	Project duration	Source of funding
N/A	To optimise traffic safety and traffic flow in the winter by using modern communication technology in highway operation. (VSS2003/601) Original language title: Optimierung der Verkehrssicherheit und des Verkehrsflusses im Winter durch den Einsatz moderner Kommunikationstechnologie im Strassenbetrieb	2005-2008	National (Switzerland) ARAMIS – ARAMIS information system
N/A	innovITS – ADVANCE	2008-2011	National (UK) innovITS
N/A	Concept for the integration of an information system for public information on the traffic conditions on state roads Original language title: Zasnova informacijskega sistema za obveščanje javnosti o prometu in stanju državnih cest	2003	National (Slovenia)
Active Barrier	Active Barrier – Ideation and Development of a New Innovative Barrier based on an Innovative Concept of Safety combined with structural function (passive function) and active function Original language title: Barriera attiva – Studio e sviluppo di un'innovativa barriera stradale basata su un nuovo concetto di sicurezza con funzione strutturale (funzione passiva) e funzione attiva	2011-2014	National (Italy) – Italian Ministry of Education, Universities and Research
ATLANTIC	A Thematic Long-term Approach to Networking for the Telematics and ITS Community	2001-2002	FP5–IST – KA1 – Systems and services for the citizens
COOPERS	Co-operative Networks for Intelligent Road Safety	2006-2010	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
FAIR	Fully Automatic Integrated Road Control	2005-2006	European (Directorate General Transport and Energy)
SARTRE	Safe road trains for the environment; Developing strategies and technologies to allow vehicle platoons to operate on normal public highways with significant environmental, safety and comfort benefits	2009-2012	FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)

Table 3-8 (Continued) Projects included in the motorway applications sub-theme assessment

N/A	Brabant In-Car II: ParckR	2011-2012	National (Netherlands)
N/A	Platform Beter Benutten	2014-	National (Netherlands)
N/A	Testfeld Telematik	2011-2013	National (Austria)
AMIDST	Analysis of massive data streams	2014-2016	FP7-ICT Information and Communication Technologies
BaSIC	BaSIC	2012-2013	National (Czech Republic)
Cooperative ITS Corridor	C-ITS Deployment Corridor NL-DE-AT	2013-2017	National (Netherlands, Germany, Austria), applied for European funding
SCOOP@F	Système Coopératif Pilote @ France	2014-2018	National (France)
SCORE@F	Système Coopératif Routier Expérimental @ France	2010-2013	National (France), applied for European funding
SISCOGA	SIStemas COoperativos GAlicia	2009-2011	National (Spain)

3.6.3.1 Technology status

The technology required to deliver C-ITS services for motorway applications is already quite advanced, as exemplified by the progress made with relatively large-scale deployment projects in this sub-theme. The intended outcomes of research projects varies by the research development stage; key trends are shown in Table 3-9.

Projects in the earlier stages of research tend to focus on development of novel technologies. For example, the Active Barrier project developed a system to detect and communicate impact with guardrails, while the SARTRE project investigated road trains/vehicle platooning technology, which has the potential to transform motorway driving.

Later stage feasibility projects investigated broader issues, such as the data analysis aspects of C-ITS and integration with traffic management systems (AMIDST, FAIR). Other projects at this research stage demonstrated the feasibility of C-ITS in preparation for larger scale projects (for example, SCORE@F prepared for SCOOP@F).

A key trend within larger scale deployment projects is the connection of countries via TEN-T corridors, which strongly supports the European Union's objective to connect European transport networks. For example, the Eco-AT project connects the Netherlands, Germany and Austria. It has recently been suggested that this connected corridor could be expanded to the Czech Republic in the future, based on positive outputs from the 'Improvement of road safety through cooperative vehicle systems providing vehicle communication with other vehicles or with the intelligent transport infrastructure' (BaSIC, 2012) project. Furthermore, the SCOOP@F project has plans to extend the deployment corridor to connect with Spain and Portugal.

Should these large-scale deployment projects be successful, the next stage is expected to be commercial deployment, which shows the achievements of C-ITS motorway applications in recent years, as research has progressed.

Table 3-9 Trends in research objectives and outcomes by stage in the research process

Research stage	Example projects	Key trends
Concept/prototype	Active Barrier, SARTRE	Technology development for novel C-ITS services. These may have applications in safety, the environment, traffic management and logistics.
Feasibility/pre-deployment	AMIDST, FAIR, COOPERS, SCORE@F, Testfield Telematik	Preparation for deployment, data analysis, integration with traffic management systems, definition of C-ITS services.
Pilot/deployment project	Cooperative ITS Corridor, NordicWay	Connecting Member States, demonstrating large-scale feasibility.
Research networks	A Thematic Long-term Approach to Networking for the Telematics and ITS Community (ATLANTIC, 2001), innovITS – ADVANCE	Knowledge sharing, research strategy, connecting Member States.

3.6.3.2 Transferability from research to practical use

The transferability of research ideas to practical use is already evident, as demonstrated by the deployment projects mentioned in the analysis of this sub-theme (for example, see Table 3-7). Basic motorway applications (such as hazardous location warnings and in-vehicle speed limits) have been tested during many small-scale trials. Therefore, the emphasis is now on larger scale pilot/FOT projects in this area. In parallel with these tests, technologies required to deliver these services are being refined, and the necessary standards and technical specifications are being developed to facilitate the efficient rollout of C-ITS across Europe.

NordicWay is a pre-deployment pilot of C-ITS services in Finland, Sweden, Norway and Denmark that intends to bridge the gap between research and widespread deployment. It is aiming to demonstrate the technical performance, impacts, costs and user acceptance of C-ITS, and will be the first large-scale pilot using cellular communication for C-ITS. The project fits exceptionally well with EU policy objectives by exploring the potential to improve safety, efficiency, comfort of mobility and the practicality of connecting road transport to other modes. This project puts the emphasis on the priority services of the ITS Directive and is fully based on European standards. Furthermore, NordicWay is aiming to build a sustainable business model (based on investment from the public sector), which addresses an area that is discussed in little detail in many other projects.

3.6.3.3 Implications of the research results for future policy development

While research projects such as NordicWay are aiming to demonstrate the potential of existing motorway applications, other projects are targeted at developing the next generation of C-ITS motorway services. The next stage will be to identify the most promising concepts and research ideas to be further developed and trialled on a larger scale. Two areas that are particularly relevant to motorway applications are the analysis of massive datasets generated by C-ITS and the development of autonomous vehicle technologies for use within C-ITS.

Projects such as AMIDST and SARTRE (discussed in Section 3.6.2.3) have made progress in these areas, but further work is required.

3.7 Public transport

### 3.7.1 Preliminary recommendations

Public transport systems play a vital role in the life of cities. They provide the mobility that helps support a city's economy and growth, and the everyday transport needs of citizens (educational, cultural, social, etc.). Public transport is undergoing important transformations and improvements through the introduction of ITS and innovative transport services such as microtransit, ridesharing, car-sharing, bike-sharing and automated bus services. However, these new services are not always well integrated into the core transport modes. Integration issues that need to be addressed include solving the 'first-kilometre, last-kilometre' problem, and cost-effectively bridging the gap between access and egress. Other important aspects that new public transport services bring forward include:

· enjoying the mobility benefits of a car without owning one;

· encouraging reduced private car usage;

· reducing household car ownership (individuals will buy trips instead of cars);

· improvements in public health, productivity and road safety.

With the introduction of innovative services, conventional services (e.g. taxis) might be disrupted, which raises policy challenges regarding safety and security, labour and employment, accessibility and equity, and insurance requirements.

Therefore, it is essential to develop research directions that will help integrate and assimilate these new services into the core of the operations of cities. Important areas of research include:

· emerging public transport systems;

· intelligent transport technologies;
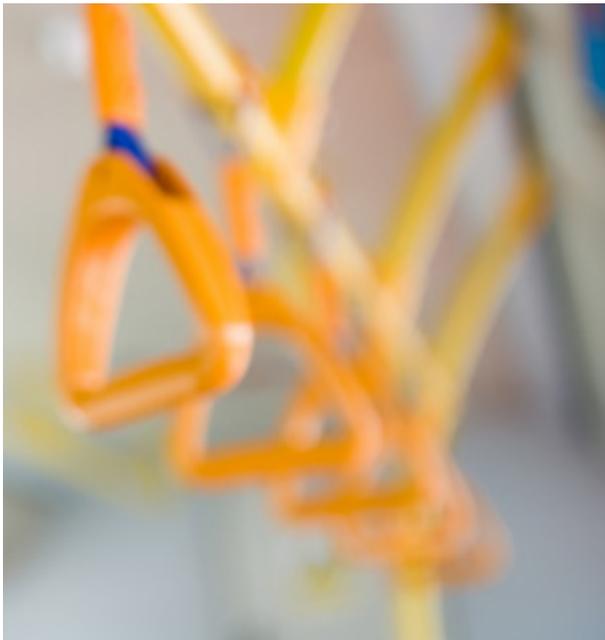
- automation;

- vehicle and traffic management;

- multimodal travel planners using big data and advanced predictive analytics;

- Mobility as a Service (MaaS) systems for providing integrated travel and payment services to travellers;

- Sustainable Urban Mobility Plans (SUMPs).

Research organisations, academia and commercial players constantly need to review upcoming trends and assess the potential demand of the integrated public transport and sharing services. They also need to understand the factors affecting user adoption of multimodal mobility (volume, frequency and types of multimodal trips by different user categories), and implement big data collection activities and dynamic measurements via smartphones, crowdsourcing, iBeacon™ technologies (activity and transit mobile app data, smart card data, and customer satisfaction and loyalty surveys, etc.). Furthermore, they need to be able to conduct visualisations and analyses using large-scale data and forecast market demand of public mass transportation in the connected and automated era.

In terms of research relating to the supply of innovative systems and services and public transport infrastructure, it is important to study the rise of technology-enabled transport services, promote seamless interaction of new shared mobility services and public transportation, and set the standards for the expansion and the implementation of MaaS systems. There is also a need to address issues related to policy fares, discounts, collection and evasion, security and privacy at a pan-European level.

Finally, to achieve potential benefits of improved public transport services, there is a need for greater consistency in regulations across Member States to allow for the informed planning of public transport services to ensure their interoperability. Research should focus on equity issues (assuring accessibility to public transport services for all users with/without credit cards, mobile phones, etc.), the assessment of the impacts and benefits of public transportation, paratransit, demand responsive systems (such as the reduction of personal vehicle travel), greenhouse gas and other pollutant emissions, automobile ownership, and an increase in quality of life and travel happiness. Other focus areas should include the provision of guidelines on how shared, connected and automated vehicles may achieve interoperability, integration and connectivity across EU countries.

3.7.2 Research environment and development

3.7.2.1 Overall direction of research

Public transport research projects are mainly related to the design, development and testing/implementation of advanced technologies, and smart ICT systems for personalised public transport solutions and optimised route planning tools, with a special focus on bus fleet management and priority schemes.

The key focus of the research is to provide real-time information to all users of passenger and multimodal transport, involving not only public transport users, but also car and bus drivers, public transport operators and local authorities. Whether it is about a municipal bus priority scheme or a personalised public transport solution for visually impaired travellers, the epicentre of all research and development actions for smart systems, devices and applications is the use of real-time cooperative information and communication technologies. A common target has been to increase the priority, efficiency and attractiveness of the available public transport modes (particularly for bus systems) through smart ITS solutions – without the need for large-scale capital investments.

3.7.2.2 Trends, knowledge gaps and policy requirements

There is a wide range of topics addressed by the several projects grouped under this sub-theme. However, the key trends identified across the last two decades are the use of C-ITS and smart technologies for the optimisation of route planning and fleet management or for personalised traveller assistance. There is a clear focus on urban bus systems in terms of bus priority monitoring, real-time bus location/bus telephone service and new-generation technologies. Another evident trend is the integration of private vehicles and public transport management throughout the network application. These contribute to the policy requirements for mobilising ITS in EU cities and for quality, accessibility of transport services and making more efficient use of public transport, while minimising the negative environmental externalities. The main research gaps that need to be filled are integrating these systems within SUMPs and, most importantly, shifting from the variety of tailor-made and fragmented systems to interoperable and integrated solutions.

3.7.2.3 Fit with current policy and targets

The research conducted under this sub-theme fits with an important element of the strategy described in the 2011 Transport White Paper (EC, 2011) – that is, the need for quality, accessibility and reliability of transport services with reference to 'clean urban transport and commuting'. More specifically, the projects particularly aim at the 'availability of information over travelling time and routing alternatives', providing evidence that ITS can lead to smart and efficient eco-mobility through optimised traffic management, seamless travel information and integrated/intermodal ticketing. The direction of research is also in line with the European Commission's 'Action Plan on Urban Mobility' (EC, 2009) in terms of 'Improving travel information' (Action 6) and 'Intelligent transport systems for urban mobility' (Action 20). Finally, the projects address directly one of the Commission's Staff Working Documents of the 2013 Urban Mobility Package (EC, 2013b) on the deployment of ITS solutions in urban areas, namely 'Mobilising Intelligent Transport Systems for EU cities'.

3.7.2.4 Overlaps and synergies within the European research community

The majority of the different research projects under this sub-theme are nationally or locally driven initiatives to improve the public transport services offered to end-users, and to optimise the fleet management and operations for the operating companies. The main common ground in the projects' objectives is related to the collection and processing of real-time information on urban (multimodal) journey planning, personalised transport solutions and vehicle/traffic management. The exchange of design principles, technological solutions and observed impacts could provide useful input for relevant EU research activities. However, the cooperation and interaction among the various national or local projects could form the basis for broader collaborative research programmes in the future.

3.7.3 Research activities and outcomes

The projects reviewed as part of the public transport sub-theme assessment are listed in Table 3-10.

Table 3-10 Projects included in the public transport sub-theme assessment

Project acronym	Project name	Project duration	Source of funding
N/A	Introduction of Integrated Transportation Systems (MSM6840770043)	2007-2013	National (Czech Republic)
N/A	Pre-study on the interaction between private and public transport in transport telematics (SVI2001/512)	2001-2003	National (Switzerland)
DUPLO	Universal device for payment, localisation and operational activities	2002-2004	National (Spain)
EBSF_2	European Bus Systems of the Future 2	2015-2018	Horizon 2020
ECOMPASS	eCO-friendly urban Multi-modal route PlAnning Services for Mobile uSers	2011-2014	FP7
FOKAT	Conditions and requirements on IT support for demand-responsive public transport	2003-2006	National (Sweden)
FRAMSYN	IT-based real-time information guidance-system for the visually impaired	2003-2005	National (Sweden)
INVETE	Intelligent In-Vehicle Terminal For Multimodal Flexible Collective Transport Services	2000-2002	FP5
MAMBA	Multimodal Mobility Assistance	2014-2017	National (Luxemburg)
PTPrealtime	Public Transport Priority in Real Time	2012-2015	National (Greece)
STREETWISE	Seamless TRavel Environment for Efficient Transport in the Western ISles of Europe	2001-2006	FP5
USMART	Personalised Smart Travel Services on Urban Environments	2014-2015	National (Greece)

3.7.3.1 Technology status

The main outputs of the research projects under this sub-theme are focused on advanced, real-time information and communication technologies that improve the individual public transport user's experience and optimise the operation and functionalities of public transport systems. More specifically, the technological outputs and achievements of the projects that have been analysed are listed below, ranging from user-oriented solutions to more comprehensive schemes and toolkits for bus drivers, public transport operators and integrated public transport systems:

- user information services

  - tools and services for end-users to enable them to be aware of their environmental impacts in urban multimodal transport systems;

  - guidance system using spatial information and real-time public transport information to assist the visually impaired when travelling alone;

  - personalised smart mobility services (e.g. route recommendations, parking availability) for major sporting and cultural events, by combining information from different data sources;

  - stop-specific telephone timetable service for city bus lines based on voice recognition and speech synthesis;

  - web-based multimodal mobility platform to interconnect different mobile services to provide personalised travel advice based on users' contexts, to proactively suggest the best transport possibility to reach a desired destination, but also to optimise overall system performance by balancing the load over different transport modes in a multimodal system;

  - innovative, non-intrusive, lightweight and easy to use smartphone app for data collection;

  - countrywide expansion of a local public transport information system;

- tools and systems for public transport operators;

  - specification of preconditions and requirements for IT systems to manage demand-responsive transport solutions;

  - definition of an IT system covering all information needs of a bus company and linking ticketing, automatic vehicle location (AVL) and planning systems in a single global system;

  - universal intelligent devices for passenger transport system functionalities (i.e. payment by contactless smart cards; localisation and operation control systems; user information and communication systems);

  - modular, multi-application in-vehicle terminal for mass transport fleets;

- infrastructure and system design tools

  - methodology and software to provide traffic priority in real time for public transport vehicles approaching junctions;

  - best practices for bus priority schemes, performance, road safety and benefits to road users/bus users;

  - VANET[19] based cooperative traffic and mobility management system, responsible for collection, storage and dissemination of information regarding traffic conditions, public transport and traffic lights schedules;

  - interaction between private motorised transport and public transport following the introduction of traffic telematics systems;

  - co-ordinated network management operations, data exchange and effective use of ITS technology to encourage the participation of public and private sectors in the provision of intermodal travel information;

  - public transport incident management system;

- vehicle and system technologies;

  - new-generation urban bus systems using new vehicle technologies and infrastructures in combination with operational best practices (optimised energy and thermal management of buses, green driver assistance systems, intelligent garage and maintenance processes, IT standard equipment and services).

3.7.3.2 Transferability from research to practical use

The projects' methodologies and specified applications, and the list of achievements above, show that the majority of the results and outcomes comprise prototype applications and technological solutions that can be tested and applied in real-life conditions. Furthermore, the technology readiness level for many of the proposed applications is high, while the methodologies and design specifications that have been developed can be transferred readily to practical use, not only in similar local conditions but also in the wider European context.

3.7.3.3 Implications of research results for future policy development

The results of the research projects identify ITS architectures that support the current policy orientation for urban mobility and offer standalone measures, which need to be adapted to a wider urban conglomeration environment to achieve seamless public transport. In addition, future policy development should aim to standardise technologies and specifications that enable the application of ITS in an urban mobility context and to promote a wider take-up of the technology.

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19 Vehicular ad hoc networks
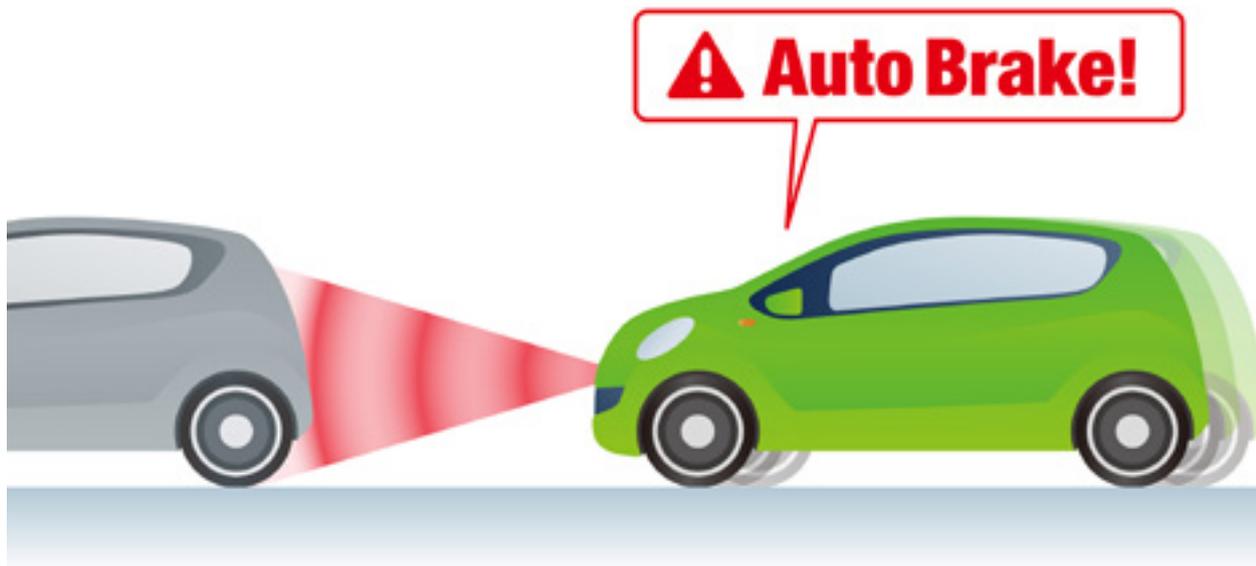
3.8 Safety, efficiency and emissions

3.8.1 Preliminary recommendations

The areas of transport safety, energy efficiency and reductions in transport-related emissions are of substantial interest to politicians and researchers. This is demonstrated by their essential presence in the main transport strategic and policy documents (Transport White Paper 2011, Europe 2020 (EC, 2010c), ITS Directive, etc.) and by the number of research projects supported from different sources (European and national) with a range of results (decision support systems/ surveillance systems, prototypes, pilots and testing, evaluation frameworks and guidelines, scientific reports etc.).

The research in this sub-theme generally fits very well with policy goals and research results of ITS (that is, to improve safety, improve energy efficiency and reduce emissions (above all CO_2 and black carbon)). Some ITS bring several benefits because they contribute simultaneously to the safer and more efficient use of transport and infrastructure. The research has shown that ITS can contribute to the main EU goals to build a competitive transport system that will increase mobility, cut carbon emissions in transport by 60% by 2050 with respect to 1990 (EC, 2011) and increase energy efficiency by 20% by 2020 (also with respect to 1990) (EC, 2010c).

ITS can significantly reduce the number of road traffic collisions (research results indicate traffic safety improvements of up to 30%) or minimise their impacts. However, the links between the intelligent vehicle systems and improvements in driver behaviour, fuel efficiency, traffic safety and overall cost savings have to be analysed more deeply (euroFOT, 2008).

ITS also have the potential to improve fuel efficiency, lowering the costs of individual transport (e.g. personal cars) and reducing the negative impacts of traffic on the environment (studies indicate possible CO_2 reductions of up to 25% with certain ICT measures – see the project 'Assessment Methodologies for ICT

in Multimodal Transport from User Behaviour to CO_2 reduction' (AMITRAN, 2011). ITS also have the potential to increase the capacity of the road network.

The future direction of research should focus on topics related to the reliability of the systems, risk assessment and the creation of scenarios to assist in understanding how to overcome the collapse of the systems. As cars can communicate via the internet without driver control, the risk of internet attacks (viruses, hackers) becomes relevant in the field of safety and security of transport.

The research under this sub-theme also impacts on industry because new business cases can arise in the framework of new enabling technologies and the multimodal context. Substantial changes can be expected in transport behaviour (driver decisions supported by ITS, eco-driving, multimodality, faster and safer travel) and stakeholder engagement. An example is the strengthened collaboration of different stakeholders (including car producers) in the transport safety field through the deployment of the Galileo system. This will have impacts on the entire positioning system industry in terms of opportunities for the development of components, and innovative applications and services. It will also be applicable to other systems and their development (e.g. the project 'Galileo for Safety of Life Applications of Driver Assistance in Road Transport' (GALLANT, 2001)). The challenges for policy makers include the regulation and planning of traffic flows and access of traffic, standardisation and cross border EU-wide trials.

Further research should provide support to policy makers and transport engineers to plan and invest in appropriate ITS (so improving safety, improving efficiency and reducing emissions), clarify the market for specific ITS applications and to understand the barriers to implementation. This support is required particularly for cities, which is why a basis is needed to understand the interest of cities in innovative ITS research ideas and their particular context.

3.8.2 Research environment and development

3.8.2.1 Overall direction of research

The projects considered in this sub-theme analysis tend to have very broad objectives. However, they all aim to demonstrate that C-ITS have the potential to contribute towards improving safety, improving efficiency and reducing emissions. About half of the projects under the safety, efficiency and emissions sub-theme deal with transport safety. The main research topics and tasks in terms of increasing safety through C-ITS focus on:

- creating methods of monitoring and assessing the benefits and overall impacts on vehicles, drivers, infrastructure and vulnerable road users (e.g. the projects 'Action for advanced Driver assistance and Vehicle control systems Implementation, Standardisation, Optimum use of the Road network and Safety' (ADVISORS, 2000) and 'ICT applications for safe cycling in Europe' (SAFECYCLE, 2010), (VRUITS, 2013));

- determination and safety assessment of effects of systems for driver assistance, including specification of data needs, preparation and transmission (e.g. the Swiss national research project 'Systems for Driver Assistance and for the Enhancement of Traffic Safety' (2003-2006));

- estimating multidimensional future priority scenarios (ADVISORS);

- systems based on monitoring the environment of the vehicle (e.g. intelligent speed adaptation – research aimed to enhance detection, tracking and classification of objects ('Cooperative Intersection Safety' (INTERSAFE-2, 2008)).

The rest of the projects were aimed at improving energy efficiency and reducing emissions. To reach this, older projects analysed the potential for ITS to regulate congestion and reach smoother traffic flows with fewer incidents and disturbances, which means improved safety, lower economic costs and reduced emissions levels. Optimised driving systems should bring additional fuel and emissions savings. For example, the 'Congestion Assistant' (STA, 2001) project was looking for a possibility to extend ACC systems to the development of a congestion assistant to assist with driving in jammed traffic – at low or zero speed and high vehicle density – and to what degree traffic flows can be improved further using V2V communication.

The other research topics and tasks cover:

- **Monitoring and evaluating the effects of ICT measures** on traffic and transport in relation to energy efficiency and CO_2 emissions – preparing methodologies at the national level (e.g. Finnish methodology) and the European level. Furthermore, most of the European projects included at least an element of an evaluation of the developed ITS (e.g. AMITRAN), 'A Decision Support System for Reducing CO_2 and Black Carbon Emissions by Adaptive Traffic Management' (CARBOTRAF, 2011), STARDUST (2004), 'Transportation Emissions Measurement and Reaction' (TEMR, 2014), 'Cooperative Mobility Pilot on Safety and Sustainability Services for Deployment' (COMPASS4D, 2013) and

'Coordination of Network Descriptors for Urban Intelligent Transportation Systems' (CONDUITS, 2009)). Research results under this topic support developers, public authorities and investors in ICT solutions to make sound decisions based on reliable impact estimates, covering the complete transport chain.

- **Real-time decision support systems** for adaptive traffic control and management (re-routing, adjusting traffic light sequences, etc.). This includes a method, system and tools adaptively influencing traffic in real time with the aim of reducing the emissions from road transport (CARBOTRAF, COMPASS4D). This service might also provide information to other drivers to anticipate current and upcoming traffic-light phases and adapt their speed accordingly (e.g. the green light optimal speed advisor functionality (GLOSA), investigated as part of projects such as 'Cooperative Self-Organizing System for low Carbon Mobility at low Penetration Rates' (COLOMBO, 2012)) or complex monitoring systems to notify dangerous conditions, by means of light or acoustic signals, and to notify such conditions to a control centre (Active Barrier).

- **Eco-driving** – developing systems and tools to help drivers sustainably eliminate unnecessary fuel consumption (and thus CO_2 emissions) and to help road operators manage traffic in the most energy-efficient way ('Cooperative Mobility Systems and Services for Energy Efficiency' (eCoMove, 2010)). This topic includes different transport modes. For example, the Greek national project, TEMR, focused on freight. It calculated vehicle emissions in a 'network' and at a vehicle level for measuring and applying energy-efficient traffic management strategies.

3.8.2.2 Trends, knowledge gaps and policy requirements.

Projects reviewed in this sub-theme fit very well with current EU policies and targets, regarding safety (they put the EU's 2050 road safety goal at the forefront of their objectives) and energy efficiency and emissions (the EU´s 2050 climate change target and the 2020 energy efficiency target).

Overall, research from this sub-theme shows relevance to all four priority areas in the field of ITS that are listed in the ITS Directive. In particular, priority areas II 'Continuity of traffic and freight management ITS services' and III 'ITS road safety and security applications' are being investigated in the most depth.

There are several gaps related to policy requirements, which might be dealt with through future research projects. First, **standardisation of the systems and their components** is crucial for compatibility and effective development of all C-ITS, as described by ADVISORS, GALLANT and SAFECYCLE. Further research efforts should focus especially on the **adaption of legislation to new systems** that can absorb a part of drivers' responsibilities (e.g. car platooning, as investigated by SARTRE) and on the issue of a shift from systems that provide information to the driver to systems that are able to take decisions instead of the driver.

Strengthened collaboration is required between different stakeholders (including car producers) in the transport safety field through the deployment of the Galileo system. This will have an impact on the entire industry of localisation systems by providing opportunities for the development of components, and innovative applications and services based on Galileo. This also applies to other systems and their development (GALLANT).

It is necessary to determine the transport-related, socio-economic and other essential impacts of trials of new ITS, applications and services in a reliable and consistent way. However, this still represents a barrier. There are more factors outside of the C-ITS field that can influence development – especially of traffic safety. Because of this, further research is required to identify the impacts of C-ITS more accurately. Of particular importance are:

· determining and assessing the safety effects of systems for driver assistance, including the specification of data needs, preparation and transmission ('Systems for Driver Assistance and for the Enhancement of Traffic Safety' (VSS1999/307,2003));

· developing a methodological framework defining the considerations for decision-making concerning the procedure (ADVISORS);

· conducting a deeper analysis of C-ITS impacts on vulnerable road users (VRUITS, SAFECYCLE);

· assessing the impacts of active in-vehicle systems aimed at preventing road traffic collisions ('Intelligent Traffic Regulations' (ITR, 2002).

The effective development of systems for driver assistance will require the estimation of multidimensional future priority scenarios (ADVISORS). Further development is also required of systems based on monitoring the vehicle environment to enhance the detection, tracking and classification of objects (INTERSAFE-2).

It should not be forgotten that a dominant part of research in this sub-theme is driven by the business sector and car producers. This brings a risk of isolated development of similar driver assistance systems with limited compatibility. It is also important to consider the effects of C-ITS on the safety of passengers (in private cars and public transport) and drivers of vehicles.

3.8.2.3 Overlaps and synergies within the European research community

Research projects on safety, efficiency and emissions have synergies not only within the sub-theme, but also with other sub-themes covered in this review, especially communication technologies, HMI, motorway applications and sensors. For example, sensors can also be used in C-ITS for safety, efficiency and emissions, and in communication technologies.

3.8.3 Research activities and outcomes

A total of 41 research projects were reviewed under the safety, efficiency and emissions sub-theme. The projects were analysed to understand the research direction, technology status and results obtained in the area of ITS, and safety, efficiency and emissions.

Of the 41 research projects, 23 were financed from various European programmes, while 18 were funded from different national programmes. Table 3-11 summarises the projects included in this analysis, their duration and source of funding.

Table 3-11 Projects reviewed under the safety, efficiency and emissions sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	Updated guidelines for evaluation of ITS projects	2002	National (Finland)
N/A	Efficient use of transport infrastructure and enforcement of environmental respects by using ITS	2003-2006	National (Hungary)
N/A	The effectiveness and benefits of traffic information system	2007-2009	National (Switzerland)
N/A	The study of relations between telematics and road safety	2002-2004	National (Hungary)
N/A	Technical and organisational basis for eCall in Switzerland (VSS2007/903)	2000-2001	National (Switzerland)
N/A	Systems for Driver Assistance and for the Enhancement of Traffic Safety (VSS1999/307)	2001-2002	National (Switzerland)
Active Barrier	Ideation and development of a new innovative barrier based on an innovative concept of safety	2011-2014	National (Italy, Italian Ministry of Education, University and Research)

Table 3-11 (Continued) Projects reviewed under the safety, efficiency and emissions sub-theme

Project acronym	Project name	Project duration	Source of funding
ADVISORS	Action for advanced Driver assistance and Vehicle control systems Implementation, Standardisation, Optimum use of the Road network and Safety	2000-2002	European (FP5 – GROWTH – KA2 – Sustainable Mobility and Intermodality)
AMITRAN	Assessment methodologies for ICT in multimodal transport from user behaviour to CO_2 reduction	2011-2014	European (FP7-ICT – Information and Communication Technologies)
AWAKE	System for effective Assessment of driver vigilance and Warning According to traffic risk Estimation	2001-2004	European (FP5 – IST – KA1 – Systems and services for the citizens)
CARBOTRAF	A decision support system for reducing CO_2 and black carbon emissions by adaptive traffic management	2011-2014	European (FP7-ICT – Information and Communication Technologies)
COLOMBO	Cooperative Self-Organizing System for low Carbon Mobility at low Penetration Rates	2012-2015	European (FP7-ICT – Information and Communication Technologies)
Compass4D	Compass4D	2013-2015	European (CIP – Competitiveness and Innovation Framework Programme)
CONDUITS	Coordination of Network Descriptors for Urban Intelligent Transportation Systems	2009-2011	European (FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT))
COSMO	Co-operative systems for sustainable mobility and energy efficiency	-	European (Competitiveness and Innovation Programme – ICT Policy Support Programme (CIP – ICT-PSP))
eCall-hyöty	Impacts of an automatic emergency call system on collision consequences	2005	National (Finland, AINO R&D programme on real-time transport information 2004-2007)
ECOMOVE	Cooperative Mobility Systems and Services for Energy Efficiency	2010-2013	European (FP7-ICT – Information and Communication Technologies)
ECOSTAND	Coordination Action for creating a common assessment methodology and joint research agenda with Japan and the USA on ITS applications focusing on energy efficiency and CO_2 reduction	2010-2013	European (FP7-ICT – Information and Communication Technologies)
EIMPACT	Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe	2006-2008	European (FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2))
euroFOT	European Large-Scale Field Operational Test on Active Safety Systems	2008-2011	European (FP7-ICT – Information and Communication Technologies)
FOTSIS	European Field Operational Test on Safe, Intelligent and Sustainable Road Operation	2011-2014	European (FP7-ICT – Information and Communication Technologies)
GALLANT	Galileo for Safety of Life Applications of Driver Assistance in Road Transport	2001-2003	European (FP5 – GROWTH – KA2 – Sustainable Mobility and Intermodality)
iCar Support	Intelligent Car Support	2009-2012	European (FP7-ICT – Information and Communication Technologies)
INTERSAFE-2	Cooperative Intersection Safety	2008-2011	European (FP7-ICT – Information and Communication Technologies)
ITR	Intelligent Traffic Regulations	2002-2005	National (Sweden, SRA/Vägverket 2000-2009 – SRA Research and development programme)

Table 3-11 (Continued) Projects reviewed under the safety, efficiency and emissions sub-theme

Project acronym	Project name	Project duration	Source of funding
IVHW	Inter-Vehicle Hazard Warning	2003-2004	National (France, DEUFRAKO – German-French cooperation for land transport research)
L2-0833	Optimal control of traffic systems with stochastic inputs	1998-2000	National (Slovenia)
METEOSAFETY	Study for the reduction of in the number of accidents in adverse weather conditions	2008-2009	National (Spain, PEIT – Strategic Plan of Infrastructures and Transport)
NEARCTIS	Network of Excellence for Advanced Road Cooperative Traffic Management in the Information Society	2008-2012	European (FP7-ICT – Information and Communication Technologies)
PRE-DRIVE	PREparation for DRIVing implementation and Evaluation of C-2-X Communication technology	2008-2010	European (FP7-ICT – Information and Communication Technologies)
SAFETY-TECHNOPRO	Training System on New Safety Technologies for Road Transport Addressed to Professional Bodies of the Automotive Sector	2006-2008	European (FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2))
SARTRE	Safe road trains for the environment; Developing strategies and technologies to allow vehicle platoons to operate on normal public highways with significant environmental, safety and comfort benefits	2009-2012	European (FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2))
SEiSS	Exploratory Study on the Potential Socio-Economic Impact of the Introduction of Intelligent Safety Systems in Road Vehicles	2004-2005	European (FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2))
SESUVY	System for evaluation of dangerous phenomena that threaten the safety and traffic flow on road infrastructure using a traffic telematics applications	2015-2016	National (Czech Rep., TACR BETA programme)
SimTD	Safe Intelligent Mobility Test Field Germany	2008-2014	National (Germany)
STA	Congestion Assistant	2001-2005	National (Germany)
STARDUST	Towards Sustainable Town development: A Research on Deployment of Urban Sustainable Transport	2001-2004	European (FP5 EESD KA4 – City of Tomorrow and Cultural Heritage)
TEMR	Transportation Emissions Measurement and Reaction	2014-2015	National (Greece, Ministry of Education and Religious Affairs)
VLA	Traffic Performance Assistance	2001-2005	National (Germany)
VRA	Traffic Impact, Legal Issues and Acceptance	2001-2005	National (Germany)
VRUITS	Improving the Safety and Mobility of Vulnerable Road Users through ITS applications	2013-2016	European (FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT))

3.8.3.1 Status of the technology

The technological improvement in this sector is fast. Systems focused on safety at intersections based on monitoring the environment by scanning static and dynamic intersection environments are now able to combine warning and intervention functions (INTERSAFE-2). The analysed projects have demonstrated the high impacts that ITS and technologies can have on safety, dangerous transport behaviour and hazardous situations. More precisely, research has revealed that:

- Automatic emergency call systems can prevent between 5 % and 10 % of motor vehicle fatalities ('Impacts of an automatic emergency call system on accident consequences' (eCall-hyöty, 2005)). Other C-ITS aspects can improve traffic safety by up to 30% ('The study of relations between telematics and road safety' (Hungary, 2001)).

- Adaptive cruise control and forward collision warning systems might have a positive effect on the overall collision statistics for all road types. Additionally, positive indirect effects on traffic efficiency have been identified (euroFOT).

- When a speed regulation system was active, over-speeding and harsh braking were reduced (euroFOT).

- The effectiveness of inter-vehicle hazard warning (IVHW) relies on the driver's capacity to correctly activate the system in hazardous situations. The results are highly dependent on the vehicle equipment rate ('Inter-Vehicle Hazard Warning' (IVHW, 2003)).

- There were potential improvements in providing transport for disadvantaged population groups (disadvantaged by location, disabilities or poverty) (CONDUITS).

Generally, the final impact of the ITS depends on the technology used. For example, ADAS/AVG systems can have an impact on the environment directly or indirectly – by smoothing vehicle movements (e.g. Stop&Go and ACC, lane keeping), changing speed profiles (e.g. intelligent speed adaptation (ISA)) and reducing private car use ('Cybernetic technologies for the car in the city' (Cybercars, 2004)). As was concluded by the STARDUST project, ADAS/AVG impacts on traffic efficiency vary with the systems, penetration levels and traffic conditions applied. ISA is, in general, a system that has negative impacts on traffic efficiency in terms of increased journey time. Stop&Go has the potential to increase the efficiency of queue discharge either at junctions or in moving queues because of the short reaction time. A combined system of ACC and Stop&Go makes it possible to automate the task of longitudinal control at high and low speeds. Lane keeping and Cybercars can contribute to improved traffic efficiency by reducing private car use in the network.

A substantial development regarding C-ITS is that vehicles can be equipped with interoperable on-board units that 'communicate' in real-time to roadside units (for example, to inform drivers about an incident on the route or to indicate a red-light violation ahead (COMPASS4D).

Most C-ITS require large penetration rates to assure their functionality, which make the first steps towards their deployment unattractive. The COLOMBO project overcame this hurdle by delivering a set of modern, self-organising traffic management algorithms that are designed to be applicable even at low penetration rates, which ensures their usability from the initial deployment. The results of COLOMBO include prototypes for incident and emission monitoring at intersections, for traffic-state estimation based on fragmented data collected in low V2X equipment rate scenarios and for the self-organising traffic control algorithm, SWARM. A key aspect in the COLOMBO investigations is the use of advanced optimisation techniques for tuning the parameter sets of the traffic control algorithms. As one of the most noticeable results of COLOMBO, even at very low V2X penetration rates (around 1 %), SWARM can already perform as well as or better than state-of-the-art adaptive traffic control algorithms that rely on a high number of costly inductive loop vehicle-detectors.

ITS technologies are generally well accepted and have received good feedback from their users. For example:

- Blind-spot information system – approximately 80% of drivers felt that this system increases safety. It is perceived as most useful on urban roads in heavy traffic (euroFOT).

- Navigation systems – analysis shows that navigation systems are well accepted and widely used, particularly on long trips on unfamiliar routes. These systems are able to plot a fuel efficient route (euroFOT).

- Curve speed warning – around 75% of the drivers felt that safety was increased thanks to this system. They also found it most useful while driving on rural roads. Some participants stated that they used it as an indicator and/or to practise (euroFOT).

3.8.3.2 Implications of the research results for future policy development

Monitoring the current situation regarding the deployment of C-ITS, standardisation, compatibility of systems and road safety impacts is necessary. There are legislative obstacles related to the introduction of C-ITS into practice. The present legislation framework puts all responsibility on the drivers. A future responsibility of C-ITS in the case of a collision needs to be investigated and adapting legislation to new systems that can absorb a part of the driver's responsibility (e.g. car platooning).

Furthermore, intensive collaboration of different stakeholders in transport safety, including car producers, should be supported.

The appropriate introduction of new technology to the market is crucial, as many drivers still do not know how to operate anti-lock braking (ABS) or electronic stability programme (ESP) systems correctly several years after they have become standard equipment. According to the results of the STARDUST project, some of the potential benefits may be reduced due to inappropriate system use.

3.9 Sensors

3.9.1 Preliminary recommendations

Sensors are integral to the efficient functioning of ITS. They provide data on a diverse range of parameters such as vehicle dynamics, congestion and air quality. This information is used for a variety of purposes, which are closely linked to the EU transport strategy, including:

- improving road safety (for example, by warning drivers about nearby vehicles or vulnerable road users);

- introducing smarter traffic management systems;

- identifying areas of congestion and delivering real-time traffic information based on a combination of imaging technologies and air-quality sensors.

As C-ITS are introduced into vehicles, the trend for more complex sensing systems is set to continue, with the capability to fuse the data provided by combinations of different sensors becoming increasingly important. Sensing technology was incorporated into many of the research projects on C-ITS. Recommendations from an analysis of the sensors sub-theme include prioritising the following aspects for future research:

- Ensuring interoperability will be crucial as sensing systems advance and rely on information generated by a multitude of sensors. A number of projects considered how data from different sources can be combined and analysed to ensure the available information is used efficiently. However, further work in this area is required.

- Many of the projects used sensors as part of ADAS, which were not necessarily cooperative systems. In the future, integration of these systems with communication technologies could be further explored.

- Sensing technology is integrated into many research projects. However, they generally focus on utilising the data provided by sensors, rather than improvements to the sensing technology.

Research projects dedicated to developing advanced sensors are one area that could be explored in the future.

- Research into the use of sensors in C-ITS is heavily focused on safety applications in passenger cars. In the future, further research into the use of sensors for other applications and in a greater variety of vehicle types could be considered.

3.9.2 Research environment and development

3.9.2.1 Overall direction of research

The assessment of research projects in the area of sensors for C-ITS applications revealed that the European Commission's goal to improve road safety is a key driver for research projects in this sub-theme. Over 80 % of projects stated the contribution to safety as a key research objective. However, as exemplified by Table 3-12, sensors can perform a number of other functions and have diverse applications within C-ITS. For example, in addition to safety, applications in traffic management, efficiency and routing are being widely researched, while a number of more niche applications (such as air quality/emissions monitoring and driver comfort improvement) were also identified. Furthermore, recent projects are investigating how the vast quantity of data from different sensors can be processed, analysed and combined to bring useful outputs. This particular aspect of research is key to ensuring interoperability and an efficient transport system.

3.9.2.2 Trends, knowledge gaps and policy requirements

As highlighted in Section 3.9.2.1, the focus of sensor research is to achieve safety improvements, with large-scale European-level projects funded under FP6, such as SAFESPOT and COOPERS, demonstrating the potential benefits of sensor technologies. An assessment of more recent projects such as SADA and 'Innovative concepts for smart road restraint systems to provide greater safety for vulnerable road users' (SMART RRS, 2008) indicates that research is shifting towards sensor analytics/data fusion and is seeking to establish how the substantial amounts of

Table 3-12 Application areas of sensors in C-ITS with example research project for each area

Application of sensors	Example project
Safety	WATCH-OVER: aimed to use a combination of sensor and communication technologies to avoid road traffic collisions that involve vulnerable road users.
Efficiency, traffic management and routing	INTRO: used a combination of different sensor data (from infrastructure, pavements and vehicles) with the objective of improving road capacity and safety. NIV: used mobile and stationary sensors to collect traffic data and develop responsive navigation solutions. ECOGEM: used vehicle sensor data on EV battery charge status to provide energy efficient routing and information on the location and availability of recharging stations.
Environment (air quality and emissions monitoring)	CARBOTRAF: used sensors to monitor CO_2 and black carbon emissions.
Driver comfort	I–WAY: used sensors to monitor driver fatigue and aimed to improve driver comfort by providing weather and traffic information.
Sensor analytics and data fusion	TRACKSS: aimed to develop new systems for cooperative sensing, and for predicting flow, infrastructure and environmental conditions surrounding traffic to improve efficiency and the safety of road transport operations.

Figure 3-2 Research under the sensors sub-theme over time
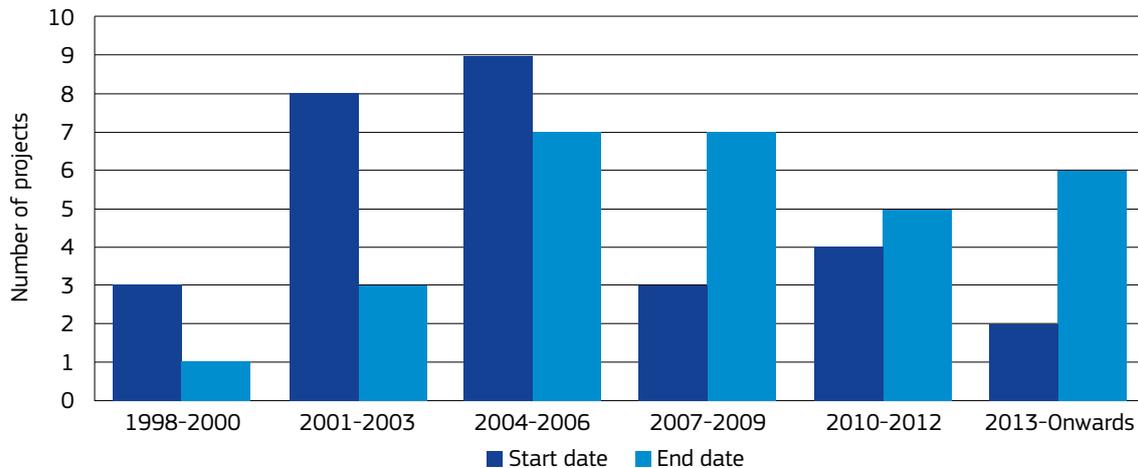
data generated by different types of sensors can be used when integrated into transport networks. Analysis of projects also suggests that funding allocation to the sensors area is slowing down (Figure 3-2). Of the 29 relevant projects in TRIP, 23 began before 2009 and six after.

3.9.2.3 Fit with current policy and targets

The ITS Directive was adopted in 2010 to accelerate and support the coordinated deployment of innovative transport technologies across Europe. The Directive details four priority areas in the field of ITS, namely:

- Priority area I: Optimal use of road, traffic and travel data;

- Priority area II: Continuity of traffic and freight management ITS services;

- Priority area III: ITS road safety and security applications;

- Priority area IV: Linking the vehicle with the transport infrastructure.

Sensors research in the context of C-ITS is directly relevant to all four priority areas, as highlighted by this review (see Section 3.9.2.1). Specifically:

- Priority area I: sensors generate data related to road and traffic conditions that can be used for traffic management purposes. Many projects reviewed addressed this aspect.

- Priority area II: sensors can facilitate improved traffic management solutions and the reduction of congestion. However, the application of sensors in freight vehicles was not explored by the projects reviewed.

- Priority area III: a desire to improve road safety is a clear driver for many projects in this sub-theme. Over 80 % of projects researched how sensors can contribute to improved road safety.

- Priority area IV: one of the main objectives of C-ITS is to facilitate communication between vehicles and infrastructure. Therefore, this aspect was ingrained in the majority of projects reviewed.

Much of the research reviewed started prior to implementation of the ITS Directive. Therefore, there has been little time to observe how research activities have been influenced by the Directive. However, it should be noted that projects in this area demonstrate a good fit with the requirements of the Directive. In addition to this, by researching the application of sensors in road safety, projects are also actively contributing to the EU Transport 2050 strategy and vision for zero fatalities in 2050, as set out in the Transport White Paper (EC, 2011).

3.9.2.4 Overlaps and synergies within the European research community

Research projects involving sensors have synergies in the sub-theme and with other sub-themes covered in this review. For example, data protection and security issues are an important part of using data from sensors in transport networks, while sensors can also be used within C-ITS for safety, efficiency and emissions.

In the sensors sub-theme, many projects have focused on identifying vulnerable road users, including 'Advanced Radar Tracking and Classification for Enhanced Road Safety' (ARTRAC, 2011-2014), PROTECTOR, 'Sensors and system architecture for vulnerable road users protection' (SAVE-U, 2002-2005), SMART RRS and 'Vehicle-to-Vulnerable Road User Cooperative Communication and Sensing Technologies to Improve Transport Safety' (WATCH-OVER, 2006-2008). These projects use similar technologies, such as radar and imaging systems, to detect vulnerable road users. However, the research has taken place over a reasonably long time period (2002-2014). This has allowed advances in technology to be incorporated in future projects.

3.9.3 Research activities and outcomes

A total of 30 projects were identified as being relevant to the sensors sub-theme. These were analysed to understand the research directions, technology status and results obtained. Of these projects, 20 were financed by various European programmes and 10 were funded by national programmes. Table 3-13 summarises the projects included in this analysis, their duration and source of funding.

Table 3-13 Projects included in the sensors sub-theme assessment

Project acronym	Project name	Project duration	Source of funding
Active Barrier	Active Barrier – Ideation and Development of a New Innovative Barrier based on an Innovative Concept of Safety combined with structural function (passive function) and active function Original language title: Barriera attiva – Studio e sviluppo di un'innovativa barriera stradale basata su un nuovo concetto di sicurezza con funzione strutturale (funzione passiva) e funzione attiva	2011-2014	National (Italy – Italian Ministry of Education, University and Research)
Aktiv	Adaptive and Cooperative Technologies for the Intelligent Traffic Original language title: Adaptive und Kooperative Technologien für den Intelligenten Verkehr	2006-2010	National (Germany)
APOLLO	Intelligent tyre for accident-free traffic	2002-2005	FP5–IST – KA1 – Systems and services for the citizens
ARCOS	Research Action for Secure Driving Original language title: Action de Recherche pour une COnduite Sécurisée	2002-2005	National (France PREDIT 3: G.O.4 – Technologies for safety, Operational Group 4)
ARTRAC	Advanced Radar Tracking and Classification for Enhanced Road Safety	2011-2014	FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)
CARBOTRAF	A Decision Support System for Reducing CO_2 and Black Carbon Emissions by Adaptive Traffic Management	2011-2014	FP7-ICT – Information and Communication Technologies
CARSENSE	Sensing of Car Environment at Low Speed Driving	2000-2002	FP5–IST – KA1 – Systems and services for the citizens
COM2REACT	Cooperative Communication System to Realise Enhanced Safety and Efficiency in European Road Transport	2006-2007	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
COOPERS	Co-operative Networks for Intelligent Road Safety	2006-2010	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
DENSE TRAFFIC	A Forward Looking Radar Sensor for Adaptive Cruise Control with Stop&Go and Cut In Situations Capabilities implemented using MMIC technologies	2001-2003	FP5–IST – KA1 – Systems and services for the citizens
ECOGEM	Cooperative Advanced Driver Assistance System for Green Cars	2010-2013	FP7-ICT – Information and Communication Technologies
euroFOT	European Large-Scale Field Operational Test on Active Safety Systems	2008-2011	FP7-ICT – Information and Communication Technologies
FRICTION	On-board Measurement of Friction and Road Slipperiness to Enhance the Performance of Integrated and Cooperative Safety Systems	2006-2008	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
FUE	Detection and Interpretation of the Driving Environment Original language title: Fahrumgebungserfassung und Interpretation	2001-2005	National (Germany)
I-WAY	Intelligent Cooperative System in Cars for Road Safety	2006-2009	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)

Table 3-13 (Continued) Projects included in the sensors sub-theme assessment

Project acronym	Project name	Project duration	Source of funding
INTERSAFE-2	Cooperative Intersection Safety	2008-2011	FP7-ICT – Information and Communication Technologies
INTRO	Intelligent Roads	2005-2008	FP6-SUSTDEV-3 – Global Change and Ecosystems
L2-5274	Optical sensors for automatic detection of roadway conditions, roadway control and vehicle counting

Original language title: Optični senzorji za avtomatsko ugotavljanje voznih pogojev, nadzor in štetje cestnega prometa | 2003-2005 | National (Slovenia) |
| NIV | Network Traffic Equalizer

Original language title: Netzausgleich Individualverkehr | 2001-2005 | National (Germany) |
PREVENT	Preventive and Active Safety Application	2004-2008	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
PROTECTOR	Preventive Safety For Un-protected Road User	1999-2003	FP5–IST – KA1 – Systems and services for the citizens
SADA	Smart Adaptive Data Aggregation	2015-2018	National (Germany – Federal Ministry of Education and Research BMBF)
SAFESPOT	Cooperative Systems for Road Safety	2006-2010	FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2)
SAVE-U	Sensors and system architecture for vulnerable road users protection	2002-2005	FP5–IST – KA1 – Systems and services for the citizens
SFLL	SmartFleet Living Lab	2014-2015	National (Austria – Upper Austrian Provincial Government)
SMART RRS	Innovative concepts for smart road restraint systems to provide greater safety for vulnerable road users	2008-2012	FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)
STA	Congestion Assistant

Original language title: Stauassistent | 2001-2005 | National (Germany) |
| SVI 1998/093 | Floating Car Data (FCD) in the transportation planning

Original language title: Floating Car Data (FCD) in der Verkehrsplanung | 1998-2000 | SVI – Swiss Association of Transportation Engineers (various projects) |
| TRACKSS | Technologies for Road Advanced Cooperative Knowledge Sharing Sensors | 2006-2008 | FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2) |
| WATCH-OVER | Vehicle-to-Vulnerable Road User Cooperative Communication and Sensing Technologies to Improve Transport Safety | 2006-2008 | FP6-IST – Information Society Technologies – Priority Thematic Area 2 (PTA2) |

3.9.3.1 Technology status and research achievements

Projects within the sensors sub-theme can be categorised in a number of ways to aid the assessment of technology status and research achievements. In Section 3.9.2, the applications of sensors within C-ITS were considered. However, for a deeper understanding of research activities, it is useful to have an appreciation of the sensor technologies being researched and the information that sensors can generate (i.e. what is being sensed). These two aspects are discussed in Section 3.9.3.2 and Section 3.9.3.3; example projects have also been highlighted in these sections.

3.9.3.2 Overview of sensor technologies

Assessment of the research projects showed that a number of different (infrastructure or vehicle based) sensing technologies are being considered for use in C-ITS. The most commonly researched technologies in the projects reviewed are:

- Cameras, including mono and stereo camera systems (WATCH-OVER), smart video cameras ('Technologies for Road Advanced Cooperative Knowledge Sharing Sensors' (TRACKSS, 2006)), infrared and heat sensitive cameras ('Detection and Interpretation of the Driving Environment' (FUE, 2001)), and other optical and visibility sensing methods ('Optical sensors for automatic detection of roadway conditions, roadway control and vehicle counting' (L2-5274, 2003)).

- Radar uses radio waves for detecting obstacles, vulnerable road users or other vehicles on the road. Short-range and long-range radar systems have been used in the projects reviewed. TRACKSS used millimetre wave pedestrian detection systems.

- Laser technology uses pulses of light and the incoming reflections to identify objects, such as vulnerable road users. Laser technology has been used in a number of projects such as PROTECTOR; lidar systems (using lasers in a radar-type application) have also been used, as in the FUE project.

- Data from the vehicle Controller Area Network bus (CANbus) allows information from in-vehicle sensors to be used for C-ITS applications (such as detecting slippery road conditions through wheelspin or the triggering of traction control systems).

- Driver state sensors were used in two projects to monitor changes in driver attentiveness ('Cooperative Communication System to Realise Enhanced Safety and Efficiency in European Road Transport' (COM2REACT, 2006)) or fatigue ('Intelligent Cooperative System in Cars for Road Safety' (I-WAY, 2006)). These applications generally rely on eye-tracking or facial recognition technology to sense driver concentration, but the technologies used in these projects were not specified.

As sensor technology, data storage and data analytics have advanced, transport research projects are beginning to trial other types of sensor or innovative combinations of sensor technologies to solve complex problems. As such, a number of other sensors have been incorporated into research projects, albeit less frequently. These include:

- air quality sensors that measure pollutants such as CO_2, black carbon, carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulate matter (CARBOTRAF and Active Barrier);

- environmental sensors that measure conditions such as moisture, temperature, rain, snow, fog, etc. ('On-board Measurement of Friction and Road Slipperiness to Enhance the Performance of Integrated and Cooperative Safety Systems' (FRICTION, 2006);

- GPS and digital maps that give information about vehicle positioning (FUE);

- magnetic influence sensor to detection vehicles (Détection de véhicules par capteur à influence magnétique);

- inductive loop sensors that are embedded into roads and detect vehicles (TRACKSS);

- remote, airborne sensors for real-time traffic measurements (TRACKSS);

- smart dust sensors for infrastructure applications (TRACKSS);

- telemeter to measure the distance of vehicles ahead (COM2REACT);

- ultrasound to measure vehicle proximity (FUE, COM2REACT);

- strain gauges that measure pavement and bridge conditions ('Intelligent Roads' (INTRO, 2005));

- biometric sensors to monitor heart rate and eye tracking (COOPERS);

- impact sensors and accelerometers to measure vehicle impact (Active Barrier).

3.9.3.3 Data generated by sensors

Data generated by sensors can be used in many different application areas, as highlighted in Table 3-12 in Section 3.9.2.1. Effective sensor systems may use several different sensor technologies, which in turn may be sensing a combination of different elements, thus highlighting the importance of sensor analytics in the future. Assessment of the projects in this sub-theme shows that there are seven broad categories of what is being sensed (see Table 3-14).

Table 3-14 Data generated by sensors

What is being sensed	Example of what is being detected	Example sensor technology	Main application areas
Driver	• Attentiveness • Fatigue • Heart rate	• Driver state system • Biometric sensors	• Safety • Driver comfort
Environment	• Air quality • Vehicle emissions • Weather conditions (ice, rain, snow, fog)	• Air quality sensors • Moisture • Temperature	• Environment • Traffic management, efficiency, routing • Safety
Infrastructure	• Impact • Road/pavement condition • Pavement/bridge strain	• Accelerometers • Strain gauges	• Safety • Traffic management, efficiency, routing
Object	• Obstacles • Vulnerable road users	• Radar • Laser/lidar • Camera • Ultrasound	• Safety
Road environment	• Road conditions (friction, slipperiness, skid resistance) • Road hazards (road shape, curve in road)	• Moisture • Temperature • In-vehicle sensors/data from the CAN bus • Strain gauges	• Safety • Driver comfort
Traffic conditions	• Congestion (e.g. by vehicle counting, air quality) • Number of vehicles	• Remote sensors • Inductive loops • Motion sensors in pavements, bridges • Magnetic influence sensors	• Traffic management, efficiency, routing
Vehicle	• Vehicle position (proximity sensors for inter-vehicle distance, longitudinal and lateral position, position in lane, relative location on a map proximity to infrastructure) • Vehicle dynamics and vehicle speed • Tyre conditions • EV battery monitoring/status	• Radar • Laser/lidar • Camera • GPS • In-vehicle sensors/data from the CAN bus • Ultrasound	• Safety • Driver comfort • Traffic management, efficiency, routing

In-vehicle sensors were the most common type of sensor employed in the projects analysed. These have a number of functions including monitoring the proximity to other vehicles (which is important during overtaking or merging manoeuvers), position in lane, vehicle dynamics (e.g. vehicle speed) and tyres to deduce friction on the road. Closely linked to this are sensors that directly analyse hazardous road environments, including adverse weather/road conditions and road shape (such as a curve in the road).

Another common area of sensor research is detecting obstacles and hazards in the road by vehicles or roadside sensing technologies. These objects include vulnerable road users (such as pedestrians or cyclists) or vehicles that have broken down. For example, ARTRAC developed a multipurpose 24 GHz radar sensor to detect vulnerable road users and estimate road conditions. Compared with conventional sensors, the ARTRAC sensor is equipped with a new transmit/receive antenna, which has a larger aperture and a multichannel receiver. The system can then help to mitigate collisions by initiating automatic braking or by providing steering recommendations.

Another project in this area, INTERSAFE-2, focused on safety at intersections using stereo visual sensors. The Cooperative Intersection Safety System (CISS) is able to detect static and dynamic components at intersections and classify objects based on their type (for example, pedestrian, vehicle, street light). However, further refinement is required to enhance detection and tracking, estimate multiple road structures, and improve the classification accuracy and interpretation of objects. Further work is also required to enable cooperation between various sensors and data sources, such as GPS and map information.

As sensor and communication technology advances, sensors monitoring the environment are starting to have a more prominent role in traffic management in C-ITS. For example, higher than average emissions or air quality issues could indicate congestion and could aid adaptive traffic management. The CARBOTRAF project combined real-time monitoring of traffic and air pollution with simulation models for the prediction of CO_2 and black carbon emissions to provide online recommendations for alternative traffic management options. The system was evaluated in Glasgow (UK) and Graz (Austria), although the project results have not yet been published.

A novel approach to the application of sensors in C-ITS was adopted by the Active Barrier project. Here, impact sensors on guardrails (such as central reservation barriers on motorways) intended to provide notification of road traffic collisions. These worked in combination with other types of sensor to improve traffic efficiency and traffic management solutions.

3.9.3.4 Transferability from research to practical use

Sensor systems are widely used in vehicles today, but it is rare for these to include a cooperative element. Research under this sub-theme seeks to address this issue by integrating combinations of sensors with communications systems. A number of projects have developed prototype systems, but these are yet to be integrated into vehicles. Once communication systems become more commonplace in vehicles, it is likely that cooperative sensing systems will also be further developed and integrated in vehicles. In the future, it is also likely that more advanced sensor technology could be derived from other sectors and applied in the transport sector.

3.10 Urban applications

3.10.1 Preliminary recommendations

Transport has become one of the major issues affecting sustainability in European cities. Around 40 % of total CO_2 emissions and 70 % of emissions of other pollutants in urban areas are caused by road traffic. Traffic congestion costs 1 % of EU gross domestic product (GDP) and one in three fatal road traffic incidents – mostly affecting vulnerable road users such as pedestrians and cyclists – occurs in urban areas (Bosetti et al., 2014).

ITS solutions can improve energy efficiency, reduce the environmental impact of urban transport, reduce costs, improve safety and improve public spaces. Research in this area generally shows a very good fit with European policy objectives. There are several ways that ITS can be used to contribute to the European policy objectives – optimise trip planning and routing, encourage eco-driving, provide energy management services, better manage traffic flows and junctions, provide alternatives to car owning, etc.

There is a strong trend towards automation with data fusion in mobility platforms. Data fusion influences business and brings city-level organisational changes (e.g. competetiveness of public transport). It also brings challenges of user acceptance and behaviour change. These trends enable the development of 'not-owning' concepts – such as car or bike sharing, car-pooling, mobility as a service and other new means of transport that try to compete with car transport. However, this progress requires legislative changes and discussion on new legislation framework (tackling the Vienna convention from 1962 that a car can only be driven by the driver).

The current research and policy challenges are related to:

- integrating various transport means into one (local) mobility platform with standard user interfaces;

- data sharing (from various sources, not only in the transport domain) to provide new services to end users (free competition based on open data provision – ideally by open application programming interface (API));

- people's motivation to use them and change their travel behaviour to support sustainable urban mobility.

As vehicle technology develops, there will be a need to manage the large amounts of data that will be generated (and which will need to be made available to other vehicles). This requirement will be particularly significant in the urban environment, due to the high density of vehicles on the road. There is a logical step that the interaction of C-ITS with the IoT in the transport domain will be a strong research and industry focus in the near future. The actual trend can be described as the merging of various industry domains – transport, ICT and telecommunication (transport telematics = ITS), energy (electromobility), environment and economy (strong support for cycling and walking in modern cities having an impact on local economy). Such a merging of domains requires acceptable EU standards to avoid creating isolated and/or expensive solutions. So, the research and development projects should respect the existing ITS standards and/or should formulate their results as new potential standards.

From the technical point of view, there is a need for more research on processes and traffic flow mechanisms such as:

- influences on capacity (smoothing the flow);

- reliability of the systems under different traffic conditions;

- adaptation and interaction to the traffic environment;

- effects of coupling between different systems;

- safety (looking at the driver behaviour and traffic processes, long-term database for incidents);

- user acceptance and understanding of new technologies (STARDUST).

New technologies bring a need for new concepts to be developed for the allocation of road space/demand management, and for the modification and enhancement of access control systems. These new concepts should be incorporated in traffic planning tools (STARDUST).

3.10.2 Research environment and development

3.10.2.1 Overall direction of research

One of the main areas of research in this sub-theme focuses on showcasing the industry innovations in the urban environment. This report analysed several EU research projects that provide new traffic control, traffic sensing, in-vehicle equipment, V2X communication etc. ('Urban Space: User assistance systems and network management' (UR:BAN, 2012-2015), CARBOTRAF, 'Multi-Objective Signal Control for Urban Environments'). However, these do not have any connection with projects that concern sustainable urban mobility strategies (USMART, 'SUstainable and PERsuasive Human Users moBility in future cities' (SUPERHUB, (2011-2014)) 'Simply mobile' (SMILE, 2012), etc.)).

The true challenge (and a trend of EU research policy) will be the interconnection of these. The project 'Green City Streets – Information Technology for Improved Public Participation in Transport Planning' (Greencitystreets, 2010) has shown two major problems of new potential deployment of ITS:

- people´s apathy – the lack of interest in getting involved and learning something new, which are needed to achieve a success of a new technology;

- the communication (marketing, motivation) to encourage people to change their (travel) behaviour.

This means that the evolution of technologies is much quicker than the adaptation of people (stakeholders) to new possibilities.

3.10.2.2 Trends, knowledge gaps and policy requirements

The policy trends include:

- **Educating people** by showcasing the potential of technology (city administrations first, as they are the most inflexible people, but at the forefront of city mobility policy). This can be illustrated in mobility platforms (use of mobile apps to travel sustainably and city administration car-pooling concepts connected with electromobility). Education should be targeted at different groups of users with their specific needs (vulnerably road users, children, seniors, disabled) and take into account different cultural backgrounds.

- **Motivating companies** by showcasing the technology potential (company mobility plans support sharing concepts with reward schemes, autonomous cars used in industrial areas).

- **Cross-border mobility alignment/management** to enhance new jobs and services. This depends on data sharing among organisations of public and private sector of different Member States and their standard format and openness (e.g. smart-parking technologies with occupancy and price information published in standard data format by all potential service providers to support using one local app for moving in different cities).

The support/policy of the EU should be based on three basic premises:

- **Interconnecting adjacent regions** – most of the projects focus on developing/testing in various cities across Europe without any alignment to adjacent cities/regions. When the project finishes, the new service is no longer available as there is often no business model and no support from the public sector. The policy should support sustainable (long-term) interconnections among adjacent regions to spread such alignment benefits across borders.

- **Sharing data in standard EU format** (e.g. DATEX II[20]) together with the definition of rules for managing the provision of anonymised transport-related data (open data, preferably made available through new open application programming interfaces (APIs) of transport companies) among stakeholders as well as other commercial interests. The standard should respect the organisation environment (e.g. network exchange (NETEX, see the project 'European Bus Systems of the Future' (EBSF2, 2015)), which is used in Great Britain, but cannot be used in countries like the Czech Republic, due to differences in the manner in which public transport is managed).

- **Overlapping various domains** – that is, the interconnection of technological (ICT, transport, environment, etc.), commercial, user and standardisation level into a single entity. A good example is the project eCo-FEV, where cooperative systems, as a new way of traffic control, are connected with electromobility and focus on a new charging potential, user education and reliability of the service.

- As ITS is a true technological concept, it should be **connected to city transport policies**, and to user acceptance and behaviour. This interconnection should be supported by appropriate research, especially regarding the availability of local technologies and their suitability for specific conditions of the city. Further requirements include analyses of their impacts and benefits, harmonisation of different IT systems that the city uses, etc. The potential interferences with the existing communication networks should also be considered as they have an impact on the purchase price, and operational and maintenance cost.

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[20] DATEX II was developed to provide a standardised way of communicating and exchanging traffic information between traffic centres, service providers, traffic operators and media partners.

3.10.3 Research activities and outcomes

A total of 23 research projects included in the TRIP database plus an additional national project were reviewed under the urban applications sub-theme. The projects were analysed to understand the research direction, technology status and results obtained in the area of urban applications.

Of the 24 research projects reviewed under urban applications, 14 were financed by various European programmes and 10 were funded by national programmes. Table 3-15 summarises the projects included in this analysis, their duration and source of funding.

Table 3-15 Projects reviewed under the urban applications sub-theme

Project acronym	Project name	Project duration	Source of funding
N/A	Mobility Trends in Cutting Edge Cities	2014-2015	National (Germany, Institute for Mobility Research)
CARBOTRAF	A Decision Support System for Reducing CO_2 and Black Carbon Emissions by Adaptive Traffic Management	2011-2014	European (FP7-ICT – Information and Communication Technologies)
City2.e 2.0	Smart Parking Solutions	2014-2015	National (Germany, Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
CITYMAN POZNAN	Traffic Management and Control System for the City of Poznan	1996-1999	EUREKA – A network for market-oriented R&D (network)
Co-Cities	Cooperative Cities extend and validate mobility services	2011-2013	European (FP7-ICT – Information and Communication Technologies)
CONDUITS	Coordination of Network Descriptors for Urban Intelligent Transportation Systems	2009-2011	European: FP7-TPT – Transport (Including Aeronautics) – Horizontal activities for implementation of the transport programme (TPT)
EBSF_2	European Bus Systems of the Future 2	2015-2018	European (Horizon2020 – The EU Framework Programme for Research and Innovation)
eCo-FEV	Efficient Cooperative infrastructure for Fully Electric Vehicles	2012-2015	European (FP7-ICT – Information and Communication Technologies)
ECOMPASS	eCO-friendly urban Multi-modal route PlAnning Services for Mobile uSers	2011-2014	European (FP7-ICT – Information and Communication Technologies)
GreenCityStreets	Green City Streets – Information Technology for Improved Public Participation in Transport Planning	2010-	National (Austria, City of Vienna)
iTETRIS	An Integrated Wireless and Traffic Platform for Real-time Road Traffic Management Solutions	2008-2011	European (FP7-ICT – Information and Communication Technologies)
KONIM	Smart cities concept in the Czech Republic	2014-2014	National (Czech Rep., TACR Beta programme)
MAMBA	Multimodal Mobility Assistance	2014-2017	National (Luxembourg, FNR- Fonds Nationale de la Recherche Luxembourg)
MOBILITY2.0	Co-operative ITS Systems for Enhanced Electric Vehicle Mobility	2012-2015	European (FP7-ICT – Information and Communication Technologies)
MOBINCITY	SMART MOBILITY IN SMART CITY	2012-2015	European (FP7-ICT – Information and Communication Technologies)
MOTUS	Mobility and Tourism in Urban Scenarios	2014-	National (Italy, Programme Industria 2015)
PRE-DRIVE	PREparation for DRIVing implementation and Evaluation of C-2-X Communication technology	2008-2010	European (FP7-ICT – Information and Communication Technologies)
PUMAS	Urban Platform for Advanced and Sustainable Mobility	2009-2012	National (France)
STA	Congestion Assistant	2001-2005	National (Germany)

Table 3-15 (Continued) Projects reviewed under the urban applications sub-theme

Project acronym	Project name	Project duration	Source of funding
STARDUST	Towards Sustainable Town development: A Research on Deployment of Urban Sustainable Transport	2001-2004	European (FP5 EESD KA4 – City of Tomorrow and Cultural Heritage)
USMART	Personalised Smart Travel Services on Urban Environments	2014-2015	National (Greece, Ministry of Education, Lifelong Learning and Religious Affairs)
FREILOT	Urban Freight Energy Efficiency Pilot	2009-2012	European (ICT for adaptive urban transport management infrastructure and services)
UR:BAN	Urban Space: User oriented assistance systems and network management	2012-2015	National (Germany, Federal Ministry of Economy and Technology)
SUPERHUB	SUstainable and PERsuasive Human Users moBility in future cities	2011-2014	European (7th RTD Framework Programme)

3.10.3.1 Status of the technology

The analysis of the urban applications projects identified a number of key topics:

- traffic control;

- cooperative mobility services and urban traffic management including simulation of traffic flows;

- IT in electromobility and public transport;

- route and personal planning.

Under the traffic control element, it was proved that better (adaptive) traffic control has a positive impact on air quality through the concept of detection of acceleration and deceleration events by measuring vehicle trajectories (CARBOTRAF).

New ICTs such as GPS/Galileo, universal mobile telecommunications system/long-term evolution (UMTS/LTE) and C2X enable novel methods for cooperative urban traffic management. By using intelligent infrastructure and networking with intelligent vehicles, future ADAS will be able to implement instructions or provide advisories to drivers to help with strategic traffic management. In this way, traffic diversions and network optimisation can take the requirements and characteristics of electric, hybrid or conventionally powered vehicles into account. In this way, efficiency is optimised, achieving a high level of service (avoiding clogged roads) and reducing emissions in urban areas (UR:BAN).

The project 'An Integrated Wireless and Traffic Platform for Real-time Road Traffic Management Solutions' (iTETRIS, (2008-2011) used an open-source microscopic traffic simulator to simulate realistic traffic flows with several vehicle classes (cars, buses, EVs, etc.). The tool enabled the simulation of up to 500 000 vehicles in real-time, with extensions available for emissions modelling (CO_2, oxides of nitrogen (NOx), particulate matter noise, etc.) and adaptive vehicle rerouting/traffic light control based on closed-loop simulations. For network simulation, a discrete-event network simulator was used. This provided good scalability, modularity and multi-technology support and allowed optimisations taking account of 'interfering packet list'

management, interference range reduction and packet rate reduction. The simulator was extended by the implementation of the Institute of Electrical and Electronics Engineers (IEEE) 802.11p, ETSI traffic class (TC) ITS profile standard, UMTS, Worldwide Interoperability for Microwave Access (WiMAX) and Digital Video Broadcasting – Handheld (DVB-H). The iTETRIS control system was used to synchronise the individual simulators in time and space, and to integrate information-related facility layer components. It provided interfaces to applications to retrieve information from the discrete event network simulator (e.g. CAM, DNM) and the microscopic traffic simulator (e.g. vehicle position, traffic light status) and to control both systems. The system supports better traffic monitoring, control and future planning as it provides the insights into solving traffic problems – event-based management (e.g. football matches), detection technology failures (e.g. closed loop) and detouring toll sections on highways.

The project has developed next-generation, communication protocols for V2V and V2I, delay- and disruption-tolerant networks (DTN) operating over multiple radio access technologies and geo-broadcast communication protocols. For potential users of the system there is a specific iTETRIS platform that provides performance evaluations of communication protocols, evaluation of the effect of traffic management applications and simple integration of novel applications and scenarios. The platform is open to future enhancements (open-source) and is available at http://www.ict-itetris.eu.

EBSF_2 demonstrated the efficient introduction of IT standards (BS EN 13149, Service Interface for Real Time Information (SIRI) and NeTEx) in an existing operational bus scenario based on results from the previous EBSF and the 'intelligent, innovative, integrated Bus Systems' project (3iBS, 2012-2015) projects. The main innovation was to move from vertical/proprietary solutions to fully interoperable on-board and back-office solutions. This will reduce dependencies on specific IT suppliers and enable competition between suppliers. For public transport operators and authorities, the efficient introduction of such a standard IT architecture will offer a faster, easier and cost-effective interoperability of public transport systems at a regional level.

The Mobility2.0 project aims to develop a solution to overcome the identified bottlenecks to a mass spread of electromobility. The first is the limited FEV range (which may lead to a 'range anxiety' of drivers in the absence of a procedure that ensures that FEV owners can always comfortably reach their destination). The second bottleneck is the limited availability of parking spaces with public recharging facilities (the number of public parking spaces in urban areas is generally limited and, particularly during the initial deployment stages, the electrification of parking spaces may not keep up with the number of FEVs). Without proper support, the FEVs with the lowest battery levels may not find the recharging spots they need and, in general, a significant amount of time would be wasted in searching for an available parking space. Furthermore, there is a potential dependence of actual FEV range on grid capacity (since FEV recharging is coupled to the available overnight grid capacity, any shortcoming of available electricity creates a transportation bottleneck). Therefore, a cooperative traffic management scenario must take into account the actual charge state of FEV batteries and the scarcity of urban road space, which leads to general traffic congestion (this can be alleviated by at least a partial modal shift to public transport, requiring the resulting transition to be a smooth one).

The last key topic identified, route and personalised planning, can be exemplified by the GreenCityStreets project. This project developed an internet application[21] designed to test the use of ITS techniques in improving transport planning. It consists of a game, best practices library and social network. The game and best practices are designed to educate residents, while the social network allows them to suggest ideas for improving transport. The application was developed and tested in Vienna during 2011. It was successful technically, but has failed to attract a critical mass of users.

3.10.3.2 Transferability from research to practical use

According to the results of the STARDUST project, many of the new technologies (e.g. ACC, Stop&Go, lane keeping, ISA, Cybercars) evaluated are in a relatively early stage of development. The precise performance levels and specific functionalities are unknown. The research identified that the associated assumptions are clearly stated but, in general, it has been assumed that the systems can perform in ways that are generally beneficial to traffic operations. In practice, market drivers may result in a reduced network benefit. In some situations, the results reflect what is possible rather than what may be likely. However, they make the case for the development of as much vehicle/highway cooperation as possible.

Thanks to the available tools (internet, 3G or 4G cellular communication) or future ones (e.g. G5), some significant advances can be obtained in the field of cooperative infrastructure systems according to the eCo-FEV project.

The eCo-FEV partners designed, developed, prototyped, validated and evaluated an open and flexible architecture for the integration of FEVs into cooperative infrastructure systems. This approach takes FEVs another step towards a mass-market penetration. Moreover, it includes new solutions for charging such as contactless modes.

3.10.3.3 Implications of the research results for future policy development

The CONDUITS project compared the results of the year of 2011 with new trends of 2016. It showed that ITS will be replaced by solutions based on the IoT, autonomous driving and cooperative systems in the near future. However, planning systems in cities generally remain very old fashioned, decreasing the potential of using new technologies.

CONDUITS further stated that evolving technologies enable better and easier use of ITS and bring high impacts on newer and better services for travellers. However, the success of sustainable urban development and transport was based on cities' abilities in urban planning and transport regulation, and having a long-term vision that was supported by their citizens. In general, the city environment is very slow in using ITS.

Dealing with the standardisation issues is a necessary prerequisite for a successful and massive market deployment. The standardisation of technologies is needed so that a variety can be used. For example, the project 'Cooperative Cities extend and validate mobility services' (Co-Cities, 2011-2013) successfully piloted software extensions based on the 'In-Time' commonly agreed interface (CAI). However, this interface does not respect the existing CEN standards and, as such, it is not perceived as the standard solution for the EU.

21 See http://www.greencitystreets.com/

4 Conclusions and recommendations

The review of research under the theme of Cooperative Intelligent Transport System (C-ITS) has concentrated on 10 sub-themes under the heading and an overall theme review:

- communication technologies;
- data protection and security;
- freight transport and logistics;
- human-machine interaction;
- information systems/platform;
- motorway applications;
- public transport;
- safety, efficiency and emissions;
- sensors;
- urban applications.

The overall conclusions and recommendations (as presented in Section 2.5 of this report) are as follows.

Overall, significant research outputs are being generated in the field of C-ITS. They are addressing many of the policy objectives in this area and are supporting the move towards commercialisation of C-ITS services in the EU. In terms of taking this research area forward, with the aim of further improving the outputs, the following recommendations are made.

- **Communication technologies**

The technical and social factors that should be explored in future research include:

- an assessment of the performance of next-generation communication technologies, their applicability to connected transport applications and the costs associated with their use;

- the definition of relevant standards as communication technologies develop to ensure a consistent approach across Europe and to maintain interoperability;

- an investigation of the security and privacy/data protection challenges associated with the use of different communication technologies;

- research into technical factors, such as the latency and reliability of communication technologies and improvements to them, especially where there are high levels of deployment of C-ITS services in congested areas;

- **Data protection and security**

Further research is required to establish common methodologies, data protocols and standards for addressing issues of data protection and security among C-ITS services and their supporting technologies, including:

- developing privacy metrics to quantify and compare levels of protection provided by different policies and security systems;

- developing privacy requirements and standards in the context of data collection activities (using alternative instruments, such as mobile device applications, travel surveys, ANPR equipment, smartcard readers);

- large sample 'big data' analysis on a pan-European level that will allow comparisons of user awareness and expectations regarding data sharing, privacy and security issues, and adoption rates of ITS-related platforms and systems across EU countries.

- **Freight transport and logistics**

The requirements for future research identified with relevance to freight transport and logistics include:

- investigate how to ensure the interoperability of sensors with a wide range of C-ITS services and ADAS to allow increasingly complex services to be deployed that rely on information generated by several sensors;

- investigate the potential for integrating applications in the vehicle to infrastructure (V2I) domain in systems that can be offered as a service for managing freight transport infrastructures;

- research commercial business models and integrated frameworks for linking connected vehicles to open and connected infrastructures, involving public and private infrastructures through 'collaborative logistics'.

- **Human-machine interaction (HMI)**

The priorities for future research into HMI include:

- HMI for informing the driver of non-safety related traffic characteristics, such as congestion mitigation or fuel efficiency;

- research the development of integrated vehicle and HMI concepts for all types of users, including the elderly and disabled;

- research the requirements for data and privacy security of HMI interfaces, with particular reference to the potential presence of fully automated vehicles in the future.

- **Information systems/platform**

The priorities for future research into information systems and platforms include:

- research into the development of systems capable of gathering, processing and enriching big data in real time, covering a mix of different information channels such as navigation systems, smartphones, infrastructure and in-vehicle devices.

- **Motorway applications**

The priorities for future research into motorway applications of C-ITS should include:

- investigating the application of C-ITS motorway services to other vehicle types, such as freight and focused on improvements of non-safety aspects, such as congestion and fuel efficiency;

- quantifying the wider costs and benefits of the C-ITS motorway applications under development to ensure that they can deliver benefits in a cost-effective manner;

- placing a greater emphasis on publishing and sharing the main research outputs;

- investigating the user-acceptance of C-ITS under motorway conditions and determining improvements to the systems (including the human-machine interface) to increase acceptance.

- **Public transport**

The key aspects of the application of C-ITS to public transport that require further research include:

- integrating C-ITS and innovative transport services (such as car-sharing, automated bus services) with the core public transport network, in particular the ability to solve the 'first-kilometre, last-kilometre' problem;

- investigating the role of C-ITS in integrating automation into the public transport system;

- developing multimodal travel planners using big data and advanced predictive analytics;

- developing mobility as a service (MaaS) systems to provide integrated travel and payment services to travellers.

- **Safety, efficiency and emissions**

The priorities for future research on the safety, efficiency and emissions aspects of C-ITS should include:

- carry out in-depth analyses of the links between the intelligent vehicle systems and improvements in driver behaviour, fuel efficiency, traffic safety and overall cost savings;

- investigate the risks to traffic safety related to the reliability of the C-ITS infrastructure – in particular, how to overcome any potential collapse of the systems;

- investigate the risks related to internet attacks (viruses, hackers) to the safety and security of the transport system;

- develop guidance for policy makers and transport engineers to plan and invest in appropriate C-ITS (so improving safety, improving efficiency and reducing emissions), clarify the market for specific ITS applications and to understand the barriers to implementation.

- **Sensors**

The priorities for future research into sensors for C-ITS should include:

- investigate how the interoperability of different sensors can be achieved to provide efficient data fusion capabilities;

- integrate sensing systems developed for ADAS applications with the communication technologies in C-ITS;

- develop advanced sensors and the use of the data provided by them for non-safety-related benefits (such as fuel efficiency, emissions) and for a greater variety of vehicle types (beyond passenger cars).

- **Urban applications**

The priorities for future research into urban applications of C-ITS should include:

- developing urban C-ITS services to a similar level of maturity as motorway services to help overcome the various transport-related issues affecting cities in the EU;

- investigating integration issues between C-ITS services and urban transport, including emerging technologies and trends (such as integrated public transport and sharing services, multimodal mobility, MaaS, crowdsourcing and iBeacon™ technologies);

- investigating the application of big data collection and analysis activities to support the future of urban mobility (such as dynamic measurements via smartphones, visualisations and analyses using large-scale data and market demand analyses for public mass transportation);

- investigating the processes and traffic flow mechanisms within an urban environment related to:

> influence on traffic capacity (smoothing the flow);

> reliability of the systems under different traffic conditions;

> adaptation to and interaction with the traffic environment;

> effects of coupling between different systems;

> safety (looking at the driver behaviour and traffic processes, developing a long-term database of incidents);

> investigate how to improve user acceptance and understanding of new technologies.
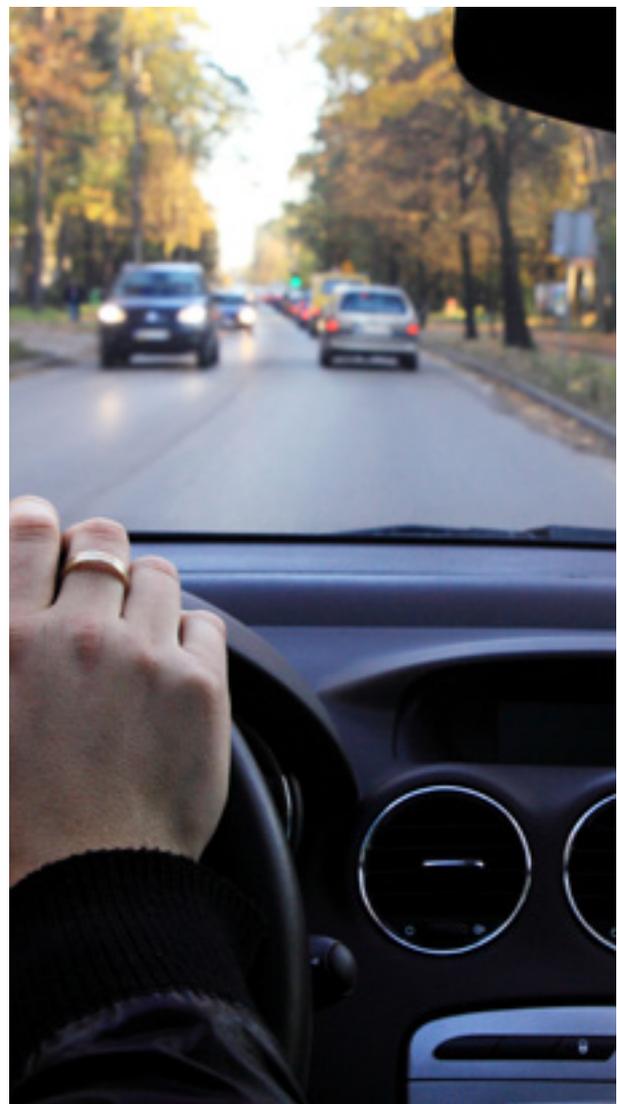
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